[COMMITTEE PRINT]

REPORTS SUBMITTED TO CONGRESS BY NASA PURSUANT TO HOUSE REPORT 99-32, TO ACCOMPANY H.R. 1714, THE NASA AUTHORIZATION ACT FOR FISCAL YEAR 1986

REPORT

PREPARED BY THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

TRANSMITTED TO THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-NINTH CONGRESS
SECOND SESSION

Serial No. BB

DECEMBER 1986

Printed for the use of the Committee on Science and Technology

U.S. GOVERNMENT PRINTING OFFICE
66-417 O WASHINGTON : 1987

H 702-1

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*Ranking Republican Member.
**Serving on Committee on the Budget for 99th Congress.

LETTER OF SUBMITTAL

House of Representatives,
Committee on Science and Technology,
Washington, DC, December 31, 1986.

Hon. Don Fuqua,
Chairman, Committee on Science and Technology,
House of Representatives.

Dear Mr. Chairman: This publication contains various reports submitted to Congress by NASA during the 99th Congress.

In general, these reports are responsive to the Committee's requests as iterated in House Report 99-32, to accompany H.R. 1714, the NASA Authorization Act for Fiscal Year 1986. A brief explanation follows each document listed in the contents.

Also listed are various reports submitted in response to Committee requests made during the 98th Congress but published by NASA in the 99th Congress.

I commend these reports to your attention.

Sincerely,

Bill Nelson,
Chairman, Subcommittee on Space Science and Applications.

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I. Pursuant to House Report 99-32 to accompany H.R. 1714, the NASA authorization bill for fiscal year 1986, the Committee on Science and Technology requested that NASA submit the following reports, summaries, plans, et cetera, to the Congress or committee.

1985

National Aeronautics and Space Administration study on utilizing existing procurement authority to encourage commerical space ventures, August 30, 1985 2

This report is in response to the committee's request that NASA review the means by which it utilizes existing procurement authority to encourage commercial space ventures.

Letter dated October 2, 1985 to Chairman Fuqua from the NASA Assistant Administrator for Legislative Affairs 37

This is in response to the committee's request that NASA comment on the subject of support for intermediate class payloads, and particularly on the views contained in the Shuttle Science Working Group's report.

Letter dated October 22, 1985 to Chairman Fuqua from the NASA Assistant Administrator for Legislative Affairs 39

This is in response to the committee's request that NASA provide a numerical aerodynamic simulation 10-year plan detailing estimated costs including a breakdown of on-going operations, hardware, replacements, and software modifications.

Letter dated November 25, 1985 to Chairman Fuqua from the NASA Assistant Administrator for Legislative Affairs 44

This is in response to the committee's request that NASA submit to Congress a report on the joint NASA/DOD study of the space transportation needs of the United States.

Letter dated December 9, 1985 to Chairman Fuqua from the NASA Associate Administrator for Space Flight and the Under Secretary of the Air Force on the NASA/DOD pricing agreement, phase III, fiscal year 1989 through fiscal year 1991 51

This is a notification of a fair and equitable pricing policy for DOD use of the National Space Transportation System in the post fiscal year 1988 timeframe, covering the period fiscal year 1989 through fiscal year 1991.

1986

Aerospace Safety Advisory Panel annual report covering calendar year 1985—dated January 1986 55

This report summarizes the panel's 1985 work, and enumerates its findings and recommendations for the attention of NASA management.

Analysis of the Office of Space Science and Applications Advanced Project Definition Activities, March 1986 152

This report responds to the committee's request that the NASA Office of Space Science and Applications submit a critical review of all potential future missions now being studied or in advanced technology development.

Analytical review of Hubble Space Telescope development, March 1986 161

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Analytical review of Hubble Space Telescope development, March 1986—Continued

This report was submitted in response to a request made in a subcommittee report titled, "Space Telescope Cost, Schedule and Performance Review, October 1984."

Report by the National Research Council's Panel on Global Habitability Assessment, March 17, 1986 209

In September 1984 the NRC Panel on Global Habitability Assessment was established to review the NASA initiative proposed under the rubic of "Global Habitability."

Analysis by NASA entitled "Royalty Recovery for Launch Services Study" 220

The purpose of this study is to report on the feasibility of providing Shuttle launch services on the basis of royalty recovery over the economic life of commercial products produced or processed in space.

II. Additional reports submitted in response to committee requests from the 98th Congress.

NASA Support for An International Geosphere Biosphere Program, August 1985 250

This is in response to the Committee's request in House Report 98-629, to accompany H.R. 5154, the National Aeronautics and Space Administration Act, fiscal year 1985, that NASA submit a report summarizing its support and contributions to the International Geosphere Biosphere Program.

Propulsion Certification Report, August 1985 262

This report is submitted in response to a request made in the committee report titled, "Review of Space Shuttle Requirements, Operations, and Future Plans report" dated October 1984.

Astrophysics Utilization of the Space Station 274

This five volume submission is in response to the committee's request in House Report 98-629, to accompany H.R. 5154, the National Aeronautics and Space Administration Act, fiscal year 1985, that NASA submit to Congress a study of current and future planned astronomical missions and an assessment of the implications of evolutionary designs that may be utilized in conjunction with the space station.

Volume 1—Executive Summary
Volume 2—The Space Station as an Observatory
Volume 3—Satellite Servicing from the Space Station
Volume 4—Assembling Astrophysics Missions at the Space Station
Volume 5—Space Platforms for Astrophysics

Letter dated January 7, 1986 to Chairman Fuqua from the NASA Assistant Administrator for Legislative Affairs on the interaction of NASA Industrial Application Centers with the Nation's small business community 414

This report highlights the efforts of the NASA industrial application centers and their interactions with the Nation's small business community.

Letter dated February 11, 1986, to the chairman of the Subcommittee on Space Science and Applications, on the Deficit Reduction Act/Competition in Contracting Act, Public Law 98-369 418

This is the annual report of the National Aeronautics and Space Administration on the implementation and performance of their Competition Advocacy Program.

I. Pursuant to House Report 99-32 to Accompany H.R. 1714, the NASA Authorization Bill for Fiscal Year 1986, the Committee on Science and Technology Requested That NASA Submit the Following Reports, Summaries, Plans, etc., to the Congress or Committee

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

STUDY

ON

UTILIZING EXISTING PROCUREMENT AUTHORITY

TO

ENCOURAGE COMMERCIAL SPACE VENTURES

AUGUST 30, 1985

SUMMARY

Based upon past experience, NASA believes that commercialization objectives can be carried out without additional legislation under the authority of the National Aeronautics and Space Act of 1958, as amended (hereafter referred to as NAS Act). Further, it is our view that current procurement authority does not provide a basis for special preference for a class of offerors such as commercial venturers or otherwise permit their "encouragement." At this time NASA is not seeking special legislation or general amendments to the procurement statutes or other statutes in this regard.

Introduction

H.R. Rep. No. 99-32 dated March 8, 1985, accompanying the bill H.R. 1714 to authorize appropriations to NASA requested the National Aeronautics and Space Administration to conduct a study into the ". . . means by which the agency can utilize existing procurement authority in a manner that effectively encourages commercial space ventures." This study addresses the Committee on Science and Technology's desire for increased private sector involvement and investment in space products or services.

Study Team

The study was performed by NASA staff from the Office of Procurement, Office of General Counsel, and Office of Commercial Programs. Their findings were reviewed by the officials-in-charge and approved by the Administrator.

Scope of Study

The study included a review of:

- The National Aeronautics and Space Act of 1958, as amended.
- The Armed Services Procurement Act of 1947, as amended
- The Competition in Contracting Act of 1984.
- Presidential Space Policy Statements.
    - June 19, 1978
    - October 11, 1978
    - July 4, 1982
    - July 20, 1984

- The Land Remote Sensing Commercialization Act of 1984.
- The Commercial Space Launch Act of 1984.
- NASA Commercial Use of Space Policy of October 1984.
- NASA Advisory Council Study of August 1, 1985.
- The International Cooperation and Competition in Civilian Activities Study of July 1985, by the Office of Technology, The Congress.
- Selected Testimony by NASA Officials Before Congress in Regard to FY 86 Authorization and Appropriations Hearings.
    - o February 28, 1985 - Isaac T.Gillam IV before the Subcommittee on Space Science and Applications - Committee on Science and Technology
    - o March 27, 1985 - Isaac T. Gillam IV before the Subcommittee on Science, Technology and Space - Committee on Commerce, Science and Transportation
    - o March 27, 1985 - Again Isaac T. Gillam IV before the Subcommittee on Science, Technology and Space - Committee on Commerce, Science and Transportation
    - o April 17, 1985 - Isaac T. Gillam IV before the Subcommittee on Science, Technology and Space - Committee on Commerce, Science and Transportation.
    - o May 22, 1985 - Isaac T. Gillam IV before the Subcommittee on Science, Research and Technology - Committee on Science and Technology
    - o June 25, 1985 - Isaac T. Gillam IV before the Subcommittee on Select Education - Committee on Education and Labor
    - o July 15, 1985 - Henry J. Clarks III before the Subcommittees on 1) Energy, Research and Production and 2) Science, Research and Technology in joint hearings - Committee on Science and Technology
- NASA Assistant General Counsel for Procurement Matters' paper entitled "Materials Processing in Space, Demonstration of Commercial Applications Program (DCAP), Issues and Alternatives" dated January 22, 1979.
- Agreements between NASA and McDonnell Douglas Corporation for Payload Assist Modules (PAMs) dated November 24, 1976 and February 15, 1977

Background History

Since 1976, NASA has pursued various approaches for enhancing commercial use of space. Under the authority of the NAS Act, NASA entered into the first commercial space agreement on November 24, 1976. This agreement was with McDonnell Douglas Corporation (MDC). MDC agreed to design, manufacture, test, and deliver spin-stabilized Payload Assist Modules (PAMs) for Delta class (2450 pounds) missions. Further, MDC would fund the effort, NASA would provide certain oversight, and NASA would not fund competing systems, provided MDC was on time and within specification. The key features here were the exclusivity to a market, private funding, and minimal requirement for Government involvment.

The proposed arrangement under the NAS Act was announced in the Commerce Business Daily and invited competing interests; MDC was selected.

On February 15, 1977, NASA and MDC entered into a second agreement for PAM-A Class (4400 pounds) upper stages with similar public notice, exclusivity arrangements, terms, and conditions.

The objectives of commercial use of space were met. The market was protected by way of a profit clause limiting the return on investments to less than 20%.

The long-term result is that the market was satisfied for both expendable launch vehicle and space transportation system launched payloads. Also, very minimal Government funds and resources were required.

Continuing upon these initiatives, NASA increased its commercial space efforts and supported the White House statement released on June 19, 1978, which declared that "The United States will encourage domestic commercial exploration of space capabilities and systems for economic benefit and to promote the technological position of the United States . . . ." On October 11, 1978, the President added ". . . Our space policy will reflect a balanced strategy of applications, science and technology development containing essential key elements that will . . . emphasize space applications that will bring important benefits to our understanding of earth's resources, climate, weather, pollution and agriculture, and provide for the private sector and to take an increasing responsibility in remote sensing and other applications . . . through more joint projects. . . ." NASA further explored alternatives to foster commercial space efforts when on October 16, 1978, the Administrator of NASA stated that "We will pursue the development and testing of key technologies in space industrial applications . . ." which ". . . also lays stress on the involvement of the private sector in some of the practical applications areas." Three days earlier, the Administrator voiced that "We will expand our effort to bring into the space program now both foreign countries and also private firms in our nation."

Reacting to the Presidential statement of October 11, 1978, the NASA Assistant General Counsel for Procurement Matters prepared a paper (Enclosure A) January 22, 1979, reviewing the authority for, issues of, and alternatives to a materials processing in space demonstration. The paper, "Demonstration of Commercial Applications Program (DCAP) Issues and Alternatives," recognized the traditional alternatives of funding research and development. The first alternative is 100% Government-funded procurement contracts competitively awarded where the intent is industrial stimulation. The second alternative is 100% industry-funded ventures, which sometimes involve the rent or lease of Government implementing facilities, for the purpose of developing a marketable product or service. It was also recognized that these traditional courses did not offer adequate incentives to offset substantial risk.

In order to provide an incentive, the NASA Assistant General Counsel for Procurement Matters believed that some form of joint endeavor agreement under the NAS Act, rather than a procurement contract, would provide the basis for involving industry. NASA also felt that a demonstration would be required to capitalize on Industry's interests. On this proposition, the decision was made that the joint endeavor opportunity would be advertised in the Federal Register. Under such agreements and on a first come basis, NASA would evaluate proposals in a uniform manner in regard to such matters as general purpose, level of investment, marketability, safety, and general need. The program proposed that industry would build and invest in the experiment or hardware while NASA would fly the payload free or at a reduced fare during the demonstration stage. NASA could decide to secure certain rights or offer exclusivity as appropriate and authorized by the Administrator.

On June 25, 1979, the NASA Administrator signed the NASA Guidelines Regarding Early Usage of Space for Industrial Purpose (Enclosure B) under the authority of the NAS Act. The NAS Act required NASA to preserve ". . . the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere." Consistent with these "Guidelines" and the Administrator's stated goal to maintain national technical superiority, through joint action with United States domestic firms, NASA published in the Federal Register, (which appeared in Vol. 44, No. 158, P. 47650, Tuesday, August 14, 1979, Enclosure B) a Notice of "Guidelines Regarding Joint Endeavors with U.S. Domestic Concerns in Materials Processing in Space."

The purpose of a JEA would be to ". . . (1) engage in research programs directed to the development and/or enhancement of U.S. commercial leadership in the field of materials processing in space, and (2) encourage commercial applications of MPS Technology . . . ." The JEA would be so structured that NASA and the industrial concern would share in the cost and risk of the endeavor. NASA incentives may include making available applicable research, providing flight time on the space transportation system, providing technical advice, and entering into mutually beneficial joint research and demonstration programs wherein each party funds their own participation.

In establishing the JEA program, NASA identified the following factors for consideration prior to implementation. These were: (1) the public or social need for the expected technology development; (2) the contribution to be made to the maintenance of U.S. technological superiority; (3) possible benefits accruing to the public or the U.S. Government from sharing in results; (4) the enhanced economic exploitation of NASA capabilities such as the space transportation system; (6) the merit of the research, development or application proposed; (7) the degree of risk and financial participation by the commercial concern; (8) the amount of proprietary data or background information to be furnished by the concern; (9) the rights in data to be granted the concern in consideration of its contribution; (10) the ability of the concern to project a potential market; (11) the willingness and ability of the concern to market and sell any resulting new or enhanced products on a reasonable basis; (12) the impact of NASA sponsorship on a given industry; (13) provision for a form of exclusivity in special cases when needed to promote innovation; (14) recoupment of the NASA contribution under appropriate circumstances; and (15) support of socio-economic objectives of the Government.

With minor changes the JEA program has worked in NASA for over six years under authority provided by the NAS Act. It is under this philosophy that firms such as Johnson & Johnson, 3M, and McDonnell Douglas have collectively invested over $100 million in private development of space-based hardware and experiments.

A similar program is the Technical Exchange Agreement (TEA) which does not involve a direct exchange of funds but rather, as the title suggests, exchanges of key technical data which mutually benefits the parties. Examples of these efforts are in metal alloy formation, John Deere; catalytic materials, Dupont; electroplating, Inco; MercuryCadmiumTellurium (HgCdTe) crystals, Honeywell, Incorporated. These firms have spent millions of dollars in their efforts under TEA's.

The foregoing activities, carried out under the authority of the NAS Act, have been successful in encouraging private involvement in commercial space endeavors.

On July 4, 1982, the President stated that "The United States Government will provide a climate conducive to expanded private sector investment and involvement in civil space activities. ..." The Congress, by Public Law 98-351, stated that "The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration seek and encourage, to the maximum extent possible, the fullest commercial use of space." The Senate Committee on Commerce, Science and Transportation stated in a report dated May 15, 1983, that "The Committee is fully supportive of efforts by the private sector to invest and seek commercial opportunities in space."

In response to the agency's commitments to commercial development of space, the Administrator of NASA signed the NASA Commercial Use of Space Policy October 29, 1984 and on November 6, 1984, established the Office of Commercial Programs to carry out the policy.

Findings

Since 1976, NASA has conducted an increasingly vigorous space commerce program under the authority of the NAS Act. Under this authority NASA has signed a significant number of agreements including Joint Endeavor Agreements (JEA's), Technical Exchange Agreements (TEA's), Cooperative Agreements (CA's), Memorandums of Understanding (MOU's) and Industrial Guest Invitations (IGI's). At the present time the Office of Commercial Programs is in various stages of negotiation or evaluation of additional Joint Endeavor and other agreements.

These agreements involve such diverse activities as electrophoresis experiments and research in organic and polymer chemistry to free-flying platforms to commercial film production. Based on Industry interest as expressed to NASA, Materials Processing in Space (MPS) shows great promise for profitable sales by commercial firms. NASA believes that MPS efforts by commercial firms will rapidly increase after the commercial success of an experimenter. NASA also believes that because flight schedules are becoming more predictable and routine and because Space Station activity is underway, more firms will overcome their earlier reluctance to invest. Moreover, since large capital investment in commercial ventures in space is often required, NASA's ability to maintain stable flight schedules and provide continued support for commercial demonstrations and joint ventures remains a primary consideration to potential investors.

The NASA Office of Commercial Programs is currently interacting with all NASA field centers and Headquarters to review implementation plans of commercial programs. The result of visits to several NASA centers indicates that the commercial space policy is very compatible with NASA's stated missions and few policy clarifications or adjustments appear to be necessary. At this time, NASA is unaware of commercial development policy requirements which cannot be carried out under existing statutes and regulation.

In contrast to the flexibility inherent in the NAS Act authority, procurement law, with certain limited statutory exceptions, contemplates full and open competition and the consideration of all offerors on an equal footing. Recent enactments, e.g. PL's 98-369, 98-525, and 98-577, have, if anything, strengthened this concept. (Indeed, by way of example, the requirement for full and open competition (98-369) and the recent interest of commercial firms in supplying upper stage vehicles has resulted in NASA competing upper stages on a mission-by-mission basis to allow all qualified firms to compete to meet NASA's needs.) In view of this, we are not aware of procurement authority which would, per se, authorize, in the selection process, a preference for commercial venturers or the encouragement of such ventures. Thus, NASA's promotion of commercial venturers in the procurement context has been necessarily constrained. We have, however, taken limited steps to promote commercial activity which we believe to be within existing legal authority. In two of our recent procurements, we have recognized that private capital investment is one of the many unweighted "Other Factors" which may be considered in arriving at a selection decision. We have also established a regulation (18-27.473-2(F)) dealing with data rights in certain co-sponsored research and development activities. This authority provides that the contractor can retain some degree of exclusive commercial rights where significant cost-sharing or co-funding is involved.

Thus, while we believe that commercialization may be "encouraged," in a limited way, utilizing the procurement process, we are not aware that existing procurement authority would allow a clear preference for a commercial venturer should other companies offer more advantageous technical or cost proposals.

Conclusion

NASA believes that its initiatives to encourage commercial use of space are achievable within present NAS Act authority. NASA further believes that present procurement authority does not allow a preference for commercial venturers in the selection process when other offerors submit more advantageous technical or cost proposals. NASA would, however, not object to any change in the procurement statutes which would allow long-term procurement arrangements with firms seeking to take advantage of the space medium for commercial purposes. However, NASA does not now seek such authority and does not believe that such is necessary for the present commercial development program to be effective.

Enclosure A

MATERIALS PROCESSING IN SPACE

DEMONSTRATION OF COMMERCIAL APPLICATIONS PROGRAM

(DCAP)

ISSUES AND ALTERNATIVES

John E. O'Brien
Assistant General Counsel
for Procurement Matters
January 22, 1979

DCAP

ISSUES AND ALTERNATIVES

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MATERIALS PROCESSING IN SPACE DEMONSTRATION OF COMMERCIAL APPLICATIONS PROGRAM (DCAP)

ISSUES AND ALTERNATIVES

I. BACKGROUND

The NASA Materials Processing in Space (MPS) Program has advanced in maturity to the point where, in conjunction with the impending initiation of space flights utilizing the Space Transportation System (STS), an overall plan must be decided upon to permit early utilization of space for commercial materials processing applications.

At the present time, there are two conventional courses of action available: Government-funded MPS experiments and demonstrations, competitively selected, which are intended to stimulate Industry interest in the use of the space medium for commercial purposes; and, Industry-funded ventures using privately owned flight hardware or hardware leased from the Government. The Government-funded activities have long range implications for the use of space for MPS purposes, whereas, Industry-funded ventures would have near-term consequences for commercial applications.

NASA experience to date has surfaced a substantial and genuine interest on the part of American Industry in pursuing commercial MPS applications, however, a significant conservatism regarding the early commitment of private resources for such purposes has also surfaced. Industry has not generally found a way to overcome a basic reluctance to become involved due to perceived risks associated with STS flights and an obvious lack of sufficient demonstrations to inspire Industry confidence in early participation on a privately funded basis.

In an effort to reconcile the Government's objective in opening space to MPS commercial ventures and Industry reluctance to become involved pending the evaluation of STS demonstrations which are Government funded, NASA has been considering how to bridge this gap in a way which would maximize the STS opportunity but minimize the time required to accomplish the objective. What has emerged is a "gap-filler" type program which would capitalize on joint endeavors between the Government and Industry pursuant to which Industry would fund their own experiment and demonstration projects and the Government would provide the opportunity for flight demonstrations utilizing Government resources.

Once a joint endeavor results in a demonstration of the feasibility of a privately developed MPS project then subsequent pursuit of the activity for commercial purposes would, of course, be at private expense, i.e., fully reimbursable STS launch services. Joint endeavors of this type would be entered into as part of the MPS Demonstration of Commercial Applications Program (DCAP). Explored below are certain issues and alternatives which should be considered in conjunction with the establishment of the DCAP.

II. LEGAL AND POLICY STRUCTURE

A. The Space Act of 1958. There are many passages in the Act which would support this type of program. For example:

(1) In addition to overall objectives related to the expansion of human knowledge in space and the utilization of space for peaceful purposes, section 102(c)(5) states the following objective:

> "(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere."

(2) Sec. 203(c)(5). NASA is authorized:

> "***to enter into and perform such contracts, leases, cooperative agreements, or other transactions as may be necessary in the conduct of its work and on such terms as it may deem appropriate, with any agency or instrumentality of the United States, or with any State, Territory, or possession, or with any political subdivision thereof, or with any person, firm, association, corporation, or educational institution***."

(3) Sec. 203(c)(5) also authorizes small business participation in NASA programs as follows:

> "***To the maximum extent practicable and consistent with the accomplishment of this Act, such contracts, leases, agreements, and other transactions shall be allocated by the Administrator in a manner which will enable small business concerns to participate equitably and proportionately in the conduct of the work of the Administration."

(4) Sec. 203(c)(6). NASA is authorized:

> "(6) to use, with their consent, the services, equipment, personnel, and facilities of Federal and other agencies with or without reimbursement, and on a similar basis to cooperate with other public and private agencies and instrumentalities in the use of services, equipment, and facilities.***"

The above specific provisions of the Space Act, coupled with the more general policies and objectives set forth in the Act, provide ample authority within which to conduct the DCAP subject to the Congressional authorization and appropriations process. Another aspect of the Space Act must also be kept in mind in examining a proper and equitable allocation of rights to inventions in entering into DCAP agreements, i.e., Sec. 305(a). This section requires NASA to take title to inventions made under a NASA contract unless a waiver is granted by the NASA Administrator under certain circumstances and conditions. Therefore, the form of a joint undertaking under the DCAP becomes very important if for no other reason than to avoid stifling Industry interest in DCAP because of any doubts about the application of section 305 of the Act.

B. Presidential Policies. On October 11, 1978, the White House announced a Presidential space policy for the next decade. Included in the White House Fact Sheet regarding the policy, the following statements are made:

> "First: Our space policy will reflect a balanced strategy of applications, science and technology development containing essential key elements that will:
>
> --Emphasize space applications that will bring important benefits to our understanding of earth resources, climate, weather, pollution and agriculture, and provide for the private sector to take an increasing responsibility in remote sensing and other applications.
>
> * * *
>
> --Increase benefits for resources expended through better integration and technology transfer among the national space programs and through more joint projects when appropriate, thereby increasing the return on the $100 billion investment in space to the benefit of the American people.

> --Assure American scientific and technological leadership in space for the security and welfare of the nation and continue R&D necessary to provide the basis for later programmatic decisions.
>
> * * *
>
> Second. More and more, space is becoming a place to work--an extension of our environment. In the future, activities will be pursued in space when it appears that national objectives can most efficiently be met though space activities.
>
> * * *
>
> As part of his overall review and in accordance with his desire to increase emphasis on uses of space for a wide variety of practical and economic benefits the President made the following decisions:" (Materials Processing in Space activities were not specifically mentioned.)

The NASA Administrator, in a special announcement released on October 16, 1978, regarding the new policy statement stated that: "We will pursue the development and testing of key technologies in space industrial applications," and; "The policy statement also lays stress on the involvement of the private sector in some of the practical applications areas and NASA is given responsibility with the Department of Commerce to work out ways in which this can be achieved." The Administrator also pointed out several remarks made by the President at the Kennedy Space Center on October 13, 1978, during which the President stated, among other things, that: "We will expand our effort to bring into the space program now both foreign countries and also private firms in our nation." There should also be considered the fact that the President, in May 1978, issued a directive which established a Policy Review Committee (Space) chaired by the Director of the Office of Science and Technology Policy (Dr. Press). This Committee provides a forum for Federal agencies to advise on proposed space policies.

Earlier in 1978, a White House press release (June 19, 1978), referring to a Presidential Directive establishing national policies to guide the conduct of U.S. activities in and related to space programs, contained the following statement:

> "Our civil space programs will be conducted to increase the body of scientific knowledge about the earth and the universe; to develop and

> operate civil applications of space technology; to maintain United States leadership in space science, applications, and technology; and to further United States domestic and foreign policy objectives within the following guidelines:
>
> - The United States will encourage domestic commercial exploitation of space capabilities and systems for economic benefit and to promote the technological position of the United States;***"

The October 1978 White House Fact Sheet also stated the following regarding international cooperation:

> "Our policy in international space cooperation will include two basic elements: (1) to pursue the best science available regardless of national origin and expand our international planning and coordinating effort; and (2) to seek cooperative support for experiments--spacecraft which have been chosen on sound scientific criteria."

Although not referred to in the October 1978 Fact Sheet, consideration must also be given to a Presidential policy issued on October 9, 1972, regarding U.S. Policy governing the provision of launch assistance. In the White House Fact Sheet on this policy, the following is stated:

> "III. With respect to the financial conditions for reimbursable launch services from U.S. launch sites, foreign users will be charged on the same basis as comparable non-U.S. Government domestic users."

The October 9, 1972, White House press release accompanying the Fact Sheet stated in part:

> "The President today announced a policy whereby the United States will provide launch assistance to other countries and international organizations for satellite projects which are for peaceful purposes and are consistent with obligations under relevant international agreements. Launches will be provided on a non-discriminatory, reimbursable basis.
>
> * * *
>
> "In establishing today a global launch assurance policy, the President affirms the need for a dependable capability which would make it possible

> for nations to have access under equal conditions to the advantages which accrue through space applications.***"

C. Congressional Briefings. Although there has to date been no disclosure of a definitive plan for a DCAP to the Congress, there have been exploratory discussions with representatives of cognizant committee staffs with encouraging results. In addition, the Associate Administrator for Space and Terrestrial Applications in his statement to the Fuqua subcommittee on February 7, 1978, stated the following:

> "***In addition to this understanding, exemplary or prototype products can be produced for demonstrations of the ultimate control achievable over composition, geometry, or defect structure of materials under unique space conditions. Such studies will also allow users to learn the advantages offered by the space environment to meet needs on Earth and, in particular, to produce limited quantities of products to allow assessments of their commercial market potential.
>
> An important part of the program will be the establishment of cooperative projects with other government agencies and with industrial users to assist them in these exploratory studies and involve their inputs in early hardware and facility design stages. Such projects will include increasing commitments on the part of such users to most effectively utilize the space environment to solve relevant problems or develop unique products with commercial interest.
>
> A study of plans required to allow commercial users access to the space environment to perform proprietary experiments will be initiated. In this program, currently developed hardware will be made available on a cost reimbursable leased basis to perform simple experiments on the Shuttle.
>
> * * *
>
> The budget we have submitted for FY 1979 will provide funds to continue the sounding rocket and MEA programs in 1979, to continue the design, fabrication, and integration of the Spacelab hardware, and to continue support of the Principal Investigators in

performing their ground-based research and control experiments. In phase with the continuing sounding rocket flights and the buildup of Shuttle flight capabilities, we are planning to focus ground-based investigations and studies to support the on-going program and to generate new investigations for space flight. The following areas of Applications Research and Technology Development are an important program supplement and are therefore being emphasized to:

* * *

- develop NASA/commercial user interfaces in the leasing of space flight hardware, marketing of space fabricated products, and the drafting of agreements on cooperative projects."

D. Issues

(1) Definition of the NASA Role. The primary threshold decision which must be made by NASA Management is whether a "gap-filler" program such as DCAP is something in which NASA should become involved: (a) at all; (b) as the sole Government participant; or (c) in concert with other Government Agencies or Departments and if so, which one(s).

It seems clear that the Space Act provides ample authority for NASA to justify its participating in a DCAP type program. It also seems clear that current Presidential policy favors the encouragement of domestic commercial exploitation of space capabilities for economic benefit, although it is less clear as to the bounds of such encouragement and how it should be carried out. There would not appear to be any impediment to NASA's assuming the initiative to implement the Government side of the interface in a DCAP program.

In view of the fact that a DCAP type program takes on the color of business development and stimulation in a somewhat different way than NASA's past R&D efforts, consideration should be given to the possible parallel or overlapping interests of other Government entities such as the Department of Commerce and the Small Business Administration, etc. This raises the question whether NASA should approach the Policy Review Committee (Space) for the purpose of obtaining guidance or concurrence, or both, with whatever plan NASA intends to follow, assuming NASA Management determines that NASA will become involved at all.

Therefore, in addition to the basic issue of a threshold decision on NASA becoming involved at all, there is a sub-issue on whether NASA should approach the Policy Review Committee (Space): (a) at all; (b) for guidance in formulating an overall plan (including the possibility of participation by others); (c) for concurrence with an already developed NASA plan, or (d) both (b) and (c). In addition, if NASA Management decides that NASA should take a solitary role, or at least the leading role, in representing the Government's interests in a DCAP type program, there are other issues which must be addressed regarding the extent of Government participation, the structure of the program, and the form of agreements to be entered into (see III, IV, and V below).

There is another sub-issue which should be considered here, i.e., whether a condition precedent to private sector eligibility to participate in DCAP is the pursuit of a NASA related MPS objective. The answer is directly related to how NASA states its MPS objective(s). If the objective is to foster commercial utilization of space for MPS purposes in its broadest connotation, then any private sector proposition would appear to qualify subject, of course, to normal standards of safety, "good taste," etc. which might otherwise apply. On the other hand, there could be more limited NASA MPS objectives established from time to time, e.g., infrared detector materials, containerless processing, heat pipe technology, etc. which could bound the zone of consideration for the DCAP program. Private sector propositions outside this set of MPS objectives would not be eligible and, therefore, Government services would be fully reimbursable. A decision is required regarding the NASA MPS objective(s) for the purpose of determining private sector eligibility to participate in DCAP.

(2) MPS versus Other Programs. In formulating a position on whether or not to implement a DCAP program for MPS, consideration should be given to whether such a program can or should be contained in its application to only MPS. It can be anticipated that private concerns interested in other uses of space may argue that DCAP arrangements should be extended to fields outside of MPS. On the other hand, it might be said that NASA has already recognized that its STS launch services reimbursement policy can provide for different treatment of users depending upon the circumstances. For example, special treatment is accorded Canada and ESA due to their significant early contributions to the development of the Space Shuttle.

It would seem that NASA can legally provide for differing treatment of users depending upon the circumstances. Of course, differences in treatment cannot be arbitrary in nature but must depend upon logical and supportable distinctions. At the present time, the justification to support containment of the DCAP to MPS would be based on NASA's perception that this is the only significant area at present where there is substantial Industry reluctance to provide full private funding for potential private gain. At any rate, the issue which should be decided is whether NASA should: (a) restrict DCAP to the MPS Program; (b) examine other programs for the potential application of DCAP; (c) proceed with MPS DCAP with the understanding that it may have application to other programs in the future; or (d) a combination of the foregoing.

(3) Domestic versus Foreign Participation. In the event that a DCAP in some form is extended to domestic firms, there is a likelihood that foreign firms may approach NASA seeking the same terms. If this should occur, the argument in favor of the foreign firms would probably hinge on an interpretation of the President's nondiscriminatory policy promulgated in 1972, quoted above, that foreign as well as domestic users of our space capabilities would be treated equally. On the other hand, the more recent Presidential pronouncements in 1978, quoted above, contain a clear policy of encouragement for domestic commercial exploitation of space for economic benefit coupled with clear statements regarding the promotion and assurance of retention of the position of United States leadership in science, and technology, and space applications.

It can be argued that the 1972 Presidential policy statement was intended to accomplish nothing more than to make the space medium available to other countries and international organizations and was not intended to further commercial interests of foreign firms in the context addressed in this paper; and that in any event, the later 1978 Presidential pronouncements do afford a basis for a more favored treatment of domestic firms. That is not to say that arguments may not be raised by foreign firms. Decisions should be made as to whether: (a) the DCAP program should be limited to participation by domestic firms only; (b) foreign firms should also be eligible to participate on an equal basis as domestic firms; or (c) additional guidance should be sought from the Policy Review Committee (Space), or otherwise, regarding the implications of the 1972 Presidential statement in the DCAP context taking into account the 1978 Presidential policy statements.

(4) Preference for Small Business Concerns. There are at least two dimensions of the large business--small business relationship which should be considered. One is whether the DCAP should include both, and the other is whether, if DCAP covers both, there should be a further preference for small business concerns. The first issue could arise in the context of questions which may be asked by the Congress or others regarding the ability of large businesses to purchase fully reimbursable STS flights without the need for the involvement of Government resources at all. This is one of the threshold issues involved in whether to establish a DCAP in the first place, i.e., is it really necessary to "force-feed" MPS to the private sector in the near term. An alternative would be to consider making DCAP available only to small business concerns as a form of preference which could probably be supported by the Space Act (Sec. 203 (c)(5) quoted above) and other similiar authorities and policy statements. It is interesting to speculate on the effect that establishment of a small business DCAP might have on large business desires to participate in the MPS Program on a fully reimbursable basis at an earlier time than now appears to be the case.

The second dimension is whether, if DCAP is opened to both large and small business participation, small business concerns should be given more favorable terms, e.g., the payment rate and amount of recoupment, etc. (see III below). This also could be justified on the basis of the Space Act and other policies favoring small business concerns. The issues which should be decided, then, are whether: (a) the DCAP should be limited to participation by domestic small business concerns exclusively; (b) the DCAP would be open to domestic large and small business concerns on an equal basis; or (c) the DCAP would include domestic large and small business concerns but with more favorable terms extended to small business concerns.

(5) Congressional Notification. Consideration should be given to the form and extent that the Congress should be informed of the DCAP if a decision is made to pursue such a program. Conceivably, the need and the extent to which disclosure is made to the Congress will depend upon the decisions which establish the scope of the program as those decisions translate into the magnitude of NASA resources intended to be committed. If, for example, NASA intends to commit $100 million a year to such a program, normal budget identification, justification, and presentations would probably be in order. On the other hand, if $1 million a year of the MPS appropriation is intended for commitment, perhaps a less formal notification to NASA's committees

might suffice. In either case, it would seem that the uniqueness of the DCAP approach justifies full disclosure and exploration with OMB and the Congress due to its potential impact on STS utilization as well as the private sector. The issue is how, when and to what extent this should be accomplished.

III. EXTENT OF GOVERNMENT PARTICIPATION

A. Subsidy, Assistance, or Demonstration. In developing the DCAP, a decision should be made how to characterize the Government involvement in a generic sense. It is clear that the Government would not be acquiring goods or services from the commercial firms in the program and so a procurement form of contract is not involved. This leaves open for consideration other forms of transactions authorized by the Space Act or the Federal Grant and Cooperative Agreement Act of 1977. Under the latter Act, grants and cooperative agreements are authorized under the circumstances outlined therein. However, the conditions for use of these legal instruments in the Act are to reflect a relationship between the Government and a recipient where "the principal purpose of the relationship is the transfer of money, property, services, or anything of value...to the recipient in order to accomplish a public purpose of support or stimulation..." (Sec. 5 and 6, P.L. 95-224). The DCAP under consideration does not envision transfers of the type contemplated by the Act; it envisions both parties to a DCAP agreement performing their own obligations on their respective sides of the interface.

By ruling out a grant or a cooperative agreement under the Act, the generic category of "assistance" is likewise ruled out because the Act delineates assistance from acquisition by defining grants and cooperative agreements as the devices by which to carry out federal assistance programs with the exclusion of subsidies, loans, loan guarantees, or insurance. A question arises whether the DCAP takes the form of a subsidy or loan which would raise the further question of NASA's authority to grant subsidies or extend loans for commercial purposes. It would appear abundently clear that DCAP does not involve either. The concept of a subsidy is generally understood to constitute a Government grant or contribution of money to or for the benefit of an individual or organization, or the guarantee of a market in some fashion. This is certainly not contemplated in the DCAP approach envisioned.

Likewise, it appears to be clear that the DCAP approach does not contemplate the extension of loans to private sector participants. The concept of Government resources involvement in the DCAP revolves around returns to the Government in terms of recoupment of its investment as well as certain rights to data and inventions. Recoupment does not equate to a loan by its very nature, since the obligation to pay is contingent on future sales and not a repayment schedule which includes interest.

There are other types of transactions available for use under Space Act authority. In response to a request from the Director of the OMB, NASA recently furnished OMB with a listing of examples of these transactions one of which pertained to Technology Utilization and Demonstration Agreements. In view of this, it would seem appropriate to designate the program a demonstration program, particularly in view of the fact that it is intended to be limited in its duration as a "gap-filler" as set forth in I above. However, a decision is needed as to the proper generic description of the program.

B. Magnitude of Resource Dedication. Since the whole concept of the DCAP requires the dedication of Government resources without full or partial reimbursement except through future recoupment (or deferred payments as the case may be--see III.B. below), a budget of some magnitude must be determined. Determination of the magnitude of Government resources available in the light of anticipated private sector interest can also affect the overall structure of the program from a procedural standpoint, i.e., whether everyone can be accommodated "first-come, first-served," or whether some form of evaluation and selection process must be established to provide for a "competition" for an allocation of the resources available (see IV below).

C. Recoupment versus Deferred Payment. The DCAP envisions Government-furnished STS launch services in support of private sector MPS demonstrations. A question arises whether the Government's interest in fostering MPS objectives is so great that the Government resources expended in support of these demonstrations justifies the investment without recapture, or whether the Government is entitled to be compensated in some way for services rendered. Because the whole concept of DCAP is to extend the realm of private enterprise into space, it may be difficult to justify foreclosing the possibility of any return on the Government's contribution.

One possible device to recover the Government investment would be to require a "fly now, pay later" commitment from each user, i.e., deferred payment. This approach may not be practicable for at least two reasons. First, the need to have a DCAP at all is because the private sector is reluctant to commit all the resources required for a fully reimbursable demonstration program. Merely deferring the payment of the full cost would probably not alter this basic reluctance. Secondly, deferred payments definitely take on the characteristics of a loan or an extension of credit. It is questionable whether NASA has the authority to enter into such arrangements whereby NASA, in effect, becomes the financing institution in lieu of private financing of a private venture.

Another device which could be used to totally or partially recover the Government contribution would be through the NASA recoupment policy for the use of NASA technology (NMI 5109.13A). A recoupment arrangement would effectively take into account the nature of the joint undertaking with the Government resource recovery being directly linked to the success, or lack of it, of subsequent commercial marketing of products which had their genesis in the demonstration phase. The risk of no recovery, or minimal recovery, by the Government would be justified because the demonstration would have been associated with an overall NASA MPS objective in the first place. This would be a reasonable risk associated with the Government's interest in demonstrating the feasibility of the use of space for MPS purposes at an earlier point in time than would otherwise have been the case. (The Government might also obtain valuable rights to inventions and data which would also justify the risk--see III.D. below). The difference between the recoupment approach and a deferred payment approach is that the former is linked to the success of the overall enterprise commercially, whereas, the latter is not. This is why the recoupment approach seems more ideally suited to the nature of the DCAP concept.

There could be many different recoupment arrangements the structure of which might depend upon the extent of the private commercial firm's investment versus the Government's, the technological feasibility of the firm's project, the likelihood of marketability, whether a large or small business concern is involved, and other criteria which would need to be developed. Initially, each agreement would have to be specially tailored; however, with the passage of time and the gaining of experience, it could well be that patterns would develop and "off-the-shelf" type agreements might become available depending upon the circumstances of particular offerings.

One possible recoupment arrangement is the coupling of a down payment with recoupment. For example, a large business DCAP proposition might be submitted for consideration which has a "moderate" chance for success as a marketable commodity in the future but which is generally compatible with a NASA MPS objective. NASA could require a non-refundable down payment on the launch services with the remainder of the NASA costs, as determined by the established STS reimbursement policy, subject to a recoupment provision. If the same proposition had been submitted by a small business concern, the arrangement might not require a down payment, and might not even require recoupment of full STS costs that would otherwise be payable to the Government. This would be in furtherance of policies which favor small business concerns.

D. Invention and Data Rights. It is assumed that the DCAP will be implemented through the use of demonstration agreements which are not contracts subject to the coverage of Sec. 305 of the Space Act. The significance of this assumption is that there will be an opportunity for a flexible mode of operation whereby invention and data rights can be allocated to reflect the equity of the parties and the program objectives, including the need to provide for downstream commercial positions which are essential to encourage private funding participants.

Since the objective of DCAP is to encourage private sector participation in projects where private firms will have to spend substantial monies up front, or assume obligations to refund significant monies at a later date (i.e. recoupment), with the hope that they will subsequently strive towards commercial utilization of the payload process, then a meaningful commercial position in inventions and data will have to be allocated at the outset to the participating private parties. Commercial rights are generally a prerequisite to establishing incentives for initial private investment looking toward subsequent commercial utilization. Hence, once a decision is made to undertake a project on a DCAP basis, the commercial position (or variations thereon) in invention and data rights becomes a fundamental necessity for the program's utilization objectives. When a specific mechanism for implementing DCAP is finally selected we can provide for the rights necessary to meet the utilization objectives. One of the difficulties of introducing a recoupment concept in DCAP may be that if an initial joint endeavor ultimately results in a totally NASA funded (no repayment by the private party) or totally privately funded (by subsequent total repayment by the private parties) then the initial allocation of invention and data rights may, or should be, subsequently changed to reflect the final funding characteristic of the project.

In addition to the recoupment complication, there may also be a problem regarding DCAP agreements involving matters related to public health, safety or welfare. NASA's current published Shuttle reimbursement policy contains the following statement (NMI 8610.8, par. 6):

> "6. PATENT AND DATA RIGHTS
>
> a. NASA will not acquire rights to inventions, patents or proprietary data privately funded by a user, or arising out of activites for which a user has reimbursed NASA under the policies set forth herein. However, in certain instances in which the NASA Administrator has determined that activities may have a significant impact on the public health, safety or welfare, NASA may obtain assurances from the user that the results will be made available to the public on terms and conditions reasonable under the circumstances."

If affirmative threshold decisions are made to establish a DCAP program, and the legal instrument to be utilized to carry out the program does not qualify as a "contract" within the meaning of Sec. 305 of the Space Act, then more rigorous analysis of policy options involving the equitable allocation of patent and data rights, and the effect of a DCAP recoupment policy on such allocations, should proceed forthwith.

IV. THE DCAP STRUCTURE

In determining the appropriate format for the DCAP approach, it should be kept in mind that a "gap-filler" program is envisioned which is related to time, as well as the interest which is likely to be generated in the private sector by offering such a program. It would appear reasonable to assume that the need to establish a DCAP in the first place carries with it a strong implication that there will be a relatively slow rate of private sector expressions of interest which will accelerate with the passage of time as early demonstrations prove the feasibility of space for MPS applications.

Assuming that the foregoing is a reasonable assumption, it would seem prudent to construct a program format which would have two phases to bridge the gap which will predictably lead to fully reimbursable private sector MPS utilization of space; Phase I, which would accommodate the anticipated slow but orderly buildup of private sector interest; and, Phase II which would accommodate a more rapid escalation of private sector interest based on earlier demonstrated interests and successful demonstration projects.

A. Phase I

The Phase I DCAP could be structured so as to essentially accommodate all interested private sector propositions. It could be characterized as a "Pilot DCAP" which would have the attributes of a "first-come, first-served" Government accommodation, which would mean that each private firm having a reasonable proposition sufficiently related to, or associated with, a NASA MPS objective would be the subject of a DCAP agreement.

Under this approach, each candidate proposition would be assured a demonstration opportunity if appropriate terms and conditions of a DCAP agreement could be agreed to with the Government. There would not be a "competition" for available MPS DCAP resources since, in effect, the Government would be scheduling demonstration opportunities for "unsolicited" DCAP proposals in accordance with their chronological acceptance into the DCAP program. The "pilot" Phase I would not have a firm termination date; rather, its termination status would be determined by the rate of escalation of private sector interest in DCAP evaluated in conjunction with the Government's ability to provide DCAP resources adequate to satisfy private sector demands on a "first-come, first-served" basis. Once it is determined that it would no longer be feasible to accommodate private sector proposals on this basis, then the pilot program would be terminated and Phase II would be initiated.

It is important to note that, under a 2-phase approach, DCAP agreements entered into in Phase I would not terminate with the initiation of Phase II. Phase I DCAP agreements would be carried on to their planned completion even though the later phases of such agreements would be executed in parallel with Phase II agreements. In other words, Phase II DCAP agreements would be entered into on a different basis than Phase I agreements; however, the initiation of Phase II would not in any way disturb Phase I DCAP agreements already in place.

B. Phase II

Initiation of Phase II would depend upon the convergence of increased private sector interest in DCAP with the Government's inability to provide resources which would accommodate the interest. It cannot be predicted with any degree of accuracy just when this might occur and, therefore, Government management judgment must be exercised in determining the most opportune time for initiation of Phase II. It is also conceivable that Phase II may not be necessary depending upon the Government's judgment that the private sector is ready, willing, and able to assume full funding responsibility for MPS activities.

The Phase II approach would shift the emphasis on participation in DCAP from a "first-come, first-served" basis to a "competitive" basis, i.e., candidate DCAP proposals would be evaluated by the Government, prioritized in accordance with evaluation criteria, and selections made so as not to exceed the Government resources available for the program. Such an evaluation process would envision periodic competitive solicitations (i.e., annual, semi-annual, etc.), and should include the following salient characteristics:

(1) Evaluation Criteria:

- Should be in consonance with stated objectives of the MPS program
- Criteria must be defined in advance
- Should give reasonable assurance that selected proposals will meet objectives
- The general criteria will have to:
    - ensure fairness (and no unfair competitive advantage) and be objective
    - address market factors involved
    - allow the selection official to assure the fostering of innovation and diffusion of technology into the market place for public benefit--not simply for the benefit of a given firm
    - provide for qualification of offerors

  - allow a reasonable risk assessment
  - permit of sufficiently visible discriminators to make rational choices between dissimilar proposals

- NASA may need help from other Government agencies and the private sector. NASA may not always have adequate knowledge of those market factors that influence how well or fast new technology can be practically adopted and diffused to the public by commercial means.

(2) Evaluation Procedure:

- Must be credible to proposers
- Must be definitive and have checks and balances analagous to the AO Steering Committee, peer group subcommittee and project office evaluations.
- Strict adherence to the criteria by the technical, management, and business subgroups--with all the factors considered by a parent group.

(3) Qualifications for Evaluators:

Must have credibility with proposers therefore:

- Each organizational element of evaluation team must have "peer" qualities--should include other Government or non-Federal personnel, as applicable, from the following fields:
  - marketing
  - banking
  - commercial processing
  - appropriate technology disciplines
  - small business
  - large business

- Must also have NASA personnel knowledgeable of NASA's programs and procedures to protect NASA's interest and provide the necessary checks and balances
- Must be cleared for avoidance of conflicts of interest
- May also include personnel from other interested agencies with potential impact, e.g., DOC - FCC - ICC - local state corporation comissions (ad hoc basis) - SEC - FDA - FTC - SBA, etc.

(4) Selection:

- The Selection Official could be the Associate Administrator for Space and Terrestrial Applications or the Director of the MPS Program
- Selection official must have rational basis for decision: structured, disciplined evaluation teams and procedure who evaluate on the basis of the objective criteria
- Selection must be based on meaningful competition
- Minimizes subjectivity and conflict of interest suspicions (several levels of review by groups with diverse interests)
- Selection statement and debriefing available to unsuccessful offerors upon request
- Scope and timing of solicitation would allow for decisions on all offers at same time (not at random) on a comparable basis. This assures rational cost vs. available funds decisions.

The above evaluation and selection process would be similar in most respects to the existing NASA Acquisition of Investigations process and, therefore, it would not be necessary to create a wholly new process for Phase II DCAP selections. Just as it would be difficult to predict with any degree of precision when Phase I should terminate and Phase II be initiated, it will likewise be difficult to predict just when Phase II should terminate. In some respects, it will be easier to determine when Phase I should be terminated because planned DCAP resources will not meet private sector demands to participate. An early effort should be made to develop criteria for NASA Management to decide when Phase II should terminate. This may involve a decision that the program should end earlier for large business concerns than for small business concerns.

C. Announcing the DCAP Program

Once the DCAP structure is determined, and the threshold decisions are made regarding the establishment of DCAP, every reasonable effort should be made to inform the private sector of the existence of the program. The primary means of notification would be a general announcement and explanation of the DCAP in the Commerce Business Daily. Other means would include "Dear Colleague" letters, notices in trade journals, dissemination of literature, symposia, and other direct contacts with the private sector.

V. THE DCAP AGREEMENT

A. Demonstration Agreements

Based upon the discussion in III.A. above, it would appear to be desirable to use a legal instrument characterized as a "Demonstration Agreement" to effectuate the joint undertakings pursuant to the DCAP program. Such an agreement has a fairly well understood meaning in NASA circles as well as in the private sector community doing business with the Department of Energy and other Government organizations. It would seem to be ideally expressive of NASA's intent to provide a "gap-filler" type program and not a permanent program which would require a continuing need for Government resource support *ad infinitum*. Such agreements could be structured in two parts as discussed below.

B. MPS Terms

Part One of a DCAP demonstration agreement would set forth the basic understanding of the parties regarding the basic MPS objectives, the respective undertakings of the parties in furtherance of the MPS objectives, recoupment obligations of the private sector participant, the allocation of patent and data rights, and any other terms and conditions essential to the joint MPS endeavor.

C. Launch Services Terms

Part Two of a DCAP demonstration agreement would contain the arrangements pursuant to which the Government would provide STS launch services. The terms and conditions would cover standard provisions which apply to all users of the STS, such as "no fault" property damage liability, third party liability provisions, insurance arrangements, and other provisions which are common to all STS users. It is clear that a special format needs to be developed for the DCAP program in view of the fact that the financing arrangements will depart from normal Shuttle reimbursement policies. Once it is decided that NASA will institute a DCAP program officially, a suitable format should be developed expeditiously so that agreements can be entered into at an early date.

D. Signature Authority

A decision must be made regarding which Government officials will be authorized to enter into DCAP demonstration agreements on behalf of the United States. Likely candidates would include the Associate Administrator for Space and Terrestrial Applications, the Director of the MPS Program, the Director of the Marshall Space Flight Center, and the head of the Commercial Space Processing Development Office at the Marshall Space Flight Center. Whomever is selected should be delegated appropriate signature authority by the NASA Administrator.

ENCLOSURE B

NASA GUIDELINES REGARDING EARLY USAGE OF SPACE FOR INDUSTRIAL PURPOSES

NASA, by virtue of the National Aeronautics and Space Act of 1958, is directed to conduct its activities so as to contribute to the preservation of the role of the United States as a leader in aeronautical and space science and technology and their applications.

Since substantial portions of the U.S. technological base and motivation reside in the U.S. private sector, NASA will enter into transactions and take necessary and proper actions to achieve the objective of national technological superiority through joint action with United States domestic concerns. These transactions and actions will be undertaken in the context of stated NASA program objectives and after a determination by the Administrator. They may include, but are not limited to: (1) engaging in joint arrangements with U.S. domestic concerns in research programs directed to the development of enhancement of U.S. commercial leadership utilizing the space environment; (2) conducting research programs having as an end objective the enhancement of U.S. capability by developing space-related high-risk or long-lead-time technology; and (3) by entering into transactions with U.S. concerns designed to encourage the commercial availability of products of NASA space flight systems.

NASA incentives for these purposes may include in addition to making available the results of NASA research: (1) providing flight time on the space transportation system on appropriate terms and conditions as determined by the Administrator; (2) providing technical advice, consultation, data, equipment and facilities to participating organizations; and (3) entering into joint research and demonstration programs where each party funds its own participation.

In making the necessary determination to proceed under this policy, the Administrator will consider the need for NASA funded support to commercial endeavors and the relative benefits to be obtained from such endeavors.

As major areas for NASA enhancement of total U.S. capability, including the private sector, may become apparent from time to time, the factors to be considered by NASA prior to providing incentives may include, but not be limited to, some or all of the following considerations: (1) the public or social need for the expected technology development; (2) the contribution to be made to the maintenance of U.S. technological superiority; (3) possible benefits accruing to the public or the U.S. Government from sharing in results; (4) the enhanced economic exploitation of NASA capabilities such as the space transportation system; (5) the desirability of private sector involvement in NASA programs; (6) the merit of the research, development or application proposed; (7) the degree of risk and financial participation by the commercial concern; (8) the amount of proprietary data or background information to be furnished by the concern; (9) the rights in data to be granted the concern in consideration of its contribution; (10) the ability of the concern to project a potential market; (11) the willingness and ability of the concern to market and sell any resulting new or enhanced products on a reasonable basis; (12) the impact of NASA sponsorship on a given industry; (13) provision for a form of exclusivity in special cases when needed to promote innovation; (14) recoupment of the NASA contribution under appropriate circumstances; and (15) support of socio-economic objectives of the Government.

Robert A. Frosch
Administrator

25 June 1979
Date

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

[Notice No. 79-70]

Guidelines Regarding Joint Endeavors With U.S. Domestic Concerns In Materials Processing In Space

Background

NASA, by virtue of the National Aeronautics and Space Act of 1958, is directed to conduct its activities so as to contribute to the preservation of the role of the United States as a leader in aeronautical and space science and technology, and their applications. In furtherance of these objectives, the Administrator of NASA on June 25, 1979, promulgated a statement of *NASA Guidelines Regarding Early Usage of Space for Industrial Purposes*. These guidelines recognized that "since substantial portions of the U.S. technological base and motivation reside in the U.S. private sector, NASA will enter into transactions and take necessary and proper actions to achieve the objective of national technological superiority through joint action with United States domestic concerns."

Materials Processing in Space (MPS) is an emerging technology which can potentially provide public benefits through applications in the private sector. However, in the foreseeable future, normal market incentives appear to be inadequate to bring about technological innovation in the private sector based on this technology. Therefore, in accordance with the above referenced Guidelines, NASA contemplates entering into joint endeavors with U.S. industrial concerns. Through these joint endeavors, NASA seeks, within the context of the MPS program objectives, to broaden the base of understanding of MPS technology, particularly with regard to its usefulness in the private sector where economic benefits may result. Present MPS program objective are: a) to understand the pervasive role of gravity in materials processing; b) to develop and demonstrate enhanced control of materials processes in weightless environment; c) to explore the unique nature of space vacuum for materials processing; and, d) to foster commercial applications of MPS technology.

Nature of the Joint Endeavor

Joint endeavors in MPS will generally be for the purpose of: 1) engaging in research programs directed to the development and/or enhancement of U.S. commercial leadership in the field of materials processing in space, and 2) encouraging commercial applications of MPS technology. Joint endeavors may cover ground-based research to create a sound scientific basis for investigations in space; the investigation of material's properties or phenomena and process technology in the unique environment of space; the making in space of exemplary materials to serve as a point of reference for ground-based materials and processes; and the application investigations and feasibility demonstrations of space-made or space-derived materials and processes.

In joint endeavors, NASA and the industrial concern share in the cost and risks of the endeavor. Terms and conditions, including the business arrangements, are negotiable within the limits of prevailing statutes and regulations and will be commensurate with the risks, involvement and investment of all the parties. NASA's intent is to offer as much latitude as practical in joint endeavor arrangements. Due to the experimental nature of the program, both technically and institutionally, each endeavor will be negotiated on a case-by-case basis. Endeavors are expected to vary in size, complexity, and arrangements to achieve diversity in the program. The number and/or size of the joint endeavors undertaken will depend upon the nature of the proposals received and resource availability. All joint endeavors will be subject to availability of appropriated funds, as well as NASA procedures regarding flight safety and verification.

NASA Provided Incentives

NASA incentives for these purposes may include in addition to making available the results of NASA research: (1) providing flight time on the space transportation system on appropriate terms and conditions as determined by the Administrator; (2) providing technical advice, consultation, data, equipment and facilities to participating organizations; and (3) entering into joint research and demonstration programs where each party funds its own participation.

Facts to be Considered in Establishing Endeavors

To qualify for joint sponsorship, the offeror must be engaged in business in the U.S. in such a manner that any promising results from the endeavor will contribute principally to the U.S. technological position; the proposed joint endeavor must comport with one or more of the MPS program objectives as stated above; and the technical uncertainties and risk involved must be significant enough to warrant the government's participation.

The factors to be considered by NASA prior to providing incentives may include, but not be limited to, some or all of the following considerations: (1) the public or social need for the expected technology development; (2) the contribution to be made to the maintenance of U.S. technological superiority; (3) possible benefits accruing to the public or the U.S. Government from sharing in results; (4) the enhanced economic exploitation of NASA capabilities such as the space transportation system; (5) the desirability of private sector involvement in NASA programs; (6) the merit of the research, development or application proposed; (7) the degree of risk and financial participation by the commercial concern; (8) the amount of proprietary data or background information to be furnished by the concern; (9) the rights in data to be granted the concern in consideration of its contribution; (10) the ability of the concern to project a potential market; (11) the willingness and ability of the concern to market and sell any resulting new or enhanced products on a reasonable basis; (12) the impact of NASA sponsorship on a given industry; (13) provision for a form of process exclusivity in special cases when needed to promote innovation. (14) recoupment of the NASA contribution under appropriate circumstances; and. (15) support of socioeconomic objectives of the Government.

Administration

The Associate Administrator, Space and Terrestrial Applications, is delegated the authority to enter into negotiations and to approve MPS joint endeavors on behalf of the Agency. Before proceeding into comprehensive evaluation of a joint endeavor, a preliminary assessment will be made of the merits of the offer. (Joint endeavor offers which are too sketchy or ill-defined to establish that the basic idea contained in the offer has merit, is in accord with MPS program objectives, or that the organization is willing to make significant contribution to the endeavor, will not be evaluated in depth and will be handled as correspondence or advertising.) This preliminary assessment will be reviewed by the Associate Administrator, Space and Terrestrial Applications, or his designee, to determine if the proposed endeavor warrants further consideration from NASA's standpoint. If this determination is positive, further evaluation will be made. After such evaluation and discussions with the offeror, if the parties mutually agree to proceed with a joint endeavor, designated representatives of NASA will enter into detailed discussions and negotiations with the offeror regarding the technical and business aspects of the offer in an effort to consummate a mutually satisfactory joint endeavor agreement. Management of the MPS joint endeavor program will be carried out by the Division of Materials Processing in Space of the Office of Space and Terrestrial Applications.

Due to resource limitations and necessity for diversity in the program, normally only one offer will be accepted to apply a particular material's process in a given technical area. If substantially similar offers are received within any 45-day period, they will be evaluated/negotiated together. The one which provides the best total consideration for the Government will be accepted. Special consideration shall be given to small and minority businesses, as appropriate.

August 3, 1979.

Robert A. Frosch,

Administrator.

[FR Doc. 79-[illegible] Filed 8-13-79; 8:45 am]

BILLING CODE 7510-01-M

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: C:JJM

OCT 2 1985

Honorable Don Fuqua
Chairman
Committee on Science
and Technology
House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

This is in response to the Committee's request that NASA comment on the subject of support for intermediate class payloads, particularly the views on the Shuttle Science Working Group's (SSWG) report. The SSWG recommended that a separate budget line be identified, that a NASA Program Office for intermediate payloads be set up, and the Shuttle Science Oversight Committee be established.

As a matter of policy our approach to development of NASA missions includes an indepth review and analysis of science requirements, development of integrated plans and strategies for space science and applications program execution, and an assessment of balance among and between disciplines. Throughout this process, care is taken to assure that all requirements are considered and that a balance is maintained between observatory class missions, shuttle payloads and other missions. This effort to assure that all aspects of the program are considered is facilitated by the established NASA Advisory Committe structure, interaction with the science community, close coordination with the National Academy of Science, and a carefully structured long range planning process within the Agency.

In view of the above, I would like to address each of the SSWG recommendations.

This establishment of a separate budget line for intermediate payloads is not necessary nor desirable, since the budget and planning process works to develop a balanced and integrated overall science program that makes efficient use of the best available approach to accomplish the mission, be it a shuttle attached payload, a free flyer, sounding rocket, balloon, etc. Within the program established for each science discipline, the developmnt of intermediate class payloads is accounted for in the Shuttle Payloads line within the appropriate disciplines. This provides a funding level that supports the missions necessary to accomplish the science objectives. "Fencing" a specific dollar amount to support only intermediate payloads would adversely affect our ability to execute science missions in the most efficient and effective manner. The exact level will fluctuate over time depending on science requirements and the development cycle for individual instruments. We believe that the system in place allows for the proper balance among and between disciplines, as well as intermediate-class payloads and other approaches.

The establishment of a separate program office for intermediate payloads would in our view be detrimental to the development of the overall science program strategy. The program is carefully developed in the context of discipline balance, response to the recommendations provided by our advisory committees, and the National priorities for space science and applications.

By the same logic, a separate Shuttle Science Oversight Committee would not positively contribute to science management within the agency. As noted above, the existing Advisory Committee structure is sufficient to assure that the best available advice is given for development of a balanced, effective and integrated strategy for space sciences.

In summary, we believe that the Agency is properly organized to support a balanced and effective space science program. Proper consideration is accorded all aspects of mission accomplishment, including maintenance of the science base and execution of the science mission in the most efficient manner utilizing all available resources at our disposal. We will continue to support intermediate class payloads consistent with mission requirements, and to assure maximum utilization of the space shuttle and Space Station.

I will be happy to discuss this subject with you in further detail if you so desire.

Sincerely,

Jack Murphy

John F. Murphy
Assistant Administrator
 for Legislative Affairs

cc:
Honorable Manuel Lujan
Honorable Bill Nelson
Honorable Robert S. Walker

DH/ R.b/ssa

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

OCT 22 1985

C:CCN:mdd

RECEIVED
[illegible]
COMMITTEE ON SCIENCE
AND TECHNOLOGY

Honorable Don Fuqua
Chairman
Committee on Science
and Technology
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

In the House Authorization Report 99-32, the Committee requested NASA provide a Numerical Aerodynamic Simulation (NAS) ten-year plan detailing estimated costs including a breakdown of ongoing operations, hardware, replacements and software modifications.

The Numerical Aerodynamic Simulation Program is an ongoing, evolutionary, and pathfinding effort, providing the world's most advanced computational capability as a national resource available to NASA, academia, industry and other government agencies, to ensure our continued leadership in aeronautical research. The program establishes a new research capability, complementing existing experimental facilities, and provides an essential tool in the advancement of computational aerodynamics and related disciplines. The NAS Processing System Network (NPSN) is an integrated state-of-the-art scientific computational capability consisting of high-speed processors, large-scale mass storage systems, advanced workstations and graphics subsystems and a high bandwidth, long-haul communications system.

To maintain a pathfinding role, the NPSN high-speed processors and other subsystems will be continually upgraded to keep pace with advancing technology. The attached table reflects NASA's current internal long range planning estimates of the level of effort required to achieve and maintain this needed national capability to fully exploit the significant benefits of computational research and address the technology challenges of the coming decade. We must add, however that these budget figures are only estimates at this time and are subject to change should budgetary or programmatic circumstances require. The funding plan is presented in two sections: (1) the Development Budget, which provides the resources for the acquisition, development, and test and integration of the various systems and subsystems, and (2) the Operations Budget, which supports the day-to-day operations, maintenance and user support of the processing system network. A more complete definition of the budget categories and sub-elements is contained in the enclosed appendix.

Sincerely,

Jack Murphy

John F. Murphy
Assistant Administrator
for Legislative Affairs

cc:
Honorable Manuel Lujan
Honorable Bill Nelson
Honorable Robert S. Walker

NUMERICAL AERODYNAMIC SIMULATION (NAS) PROGRAM
TEN YEAR FUNDING PLAN AS OF OCTOBER 1, 1985
($ IN MILLIONS)

	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95
DEVELOPMENT BUDGET										
HARDWARE ACQ. & LEASE*	17.3	20.8	19.4	20.7	21.5	21.9	22.4	23.3	25.1	25.7
SOFTWARE RESEARCH & DEV.	3.4	4.0	3.7	3.3	3.1	3.2	3.3	3.4	3.1	3.2
SYSTEM ENG. TEST & INT	7.5	5.2	3.6	4.3	4.7	5.2	5.6	5.7	6.4	6.3
TOTAL	28.2	30.0	26.7	28.3	29.3	30.3	31.3	32.4	34.6	35.2
OPERATIONS BUDGET										
DATA CENTER OPERATIONS	1.6	3.5	3.7	3.7	4.0	4.0	4.2	4.3	4.5	4.6
HARDWARE MAINTENANCE	1.9	3.2	3.4	3.5	4.0	4.1	4.1	4.3	4.5	4.6
SOFTWARE LICENSES	.4	.8	.9	.9	.9	1.0	1.0	1.0	1.1	1.1
USER SERVICES	.6	1.8	1.9	1.9	2.1	2.1	2.2	2.3	2.3	2.4
SOFTWARE MAINTENANCE	1.0	2.3	2.9	3.0	3.1	3.1	3.2	3.4	3.4	3.6
MANAGEMENT/LOGISTICS	.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.9
TOTAL	5.9	13.0	14.3	14.5	15.7	15.9	16.4	17.0	17.6	18.2
PROGRAM TOTAL	34.1	43.0	41.0	42.8	45.0	46.2	47.7	49.4	52.2	53.4
*HIGHSPEED PROCESSORS	(8.3)	(13.9)	(14.8)	(15.4)	(15.8)	(17.2)	(18.1)	(17.5)	(18.7)	(20.4)

APPENDIX

NUMERICAL AERODYNAMIC SIMULATION (NAS) PROGRAM
TEN-YEAR FUNDING PLAN

DEFINITION OF BUDGET ELEMENTS

DEVELOPMENT BUDGET

Hardware Acquisition and Lease

Includes all costs associated with equipment lease and/or purchase, and equipment site preparation for the NAS Program. Hardware maintenance is not included.

Software Research and Development

Includes all costs associated with research and development activities in operating systems, communications, languages, graphics, and specialized techniques and programs. The focus of this effort is to enable the researcher to optimize system utilization.

System Engineering, Test, and Integration

Includes all costs associated with feasibility, trade-off, and requirements studies; engineering and prototypes; minor equipment acquisition and installation; and test and integration of all systems.

OPERATIONS BUDGET

Data Center Operations

Includes all costs associated with the physical operation of all computer systems in the NAS Program. Costs associated with communications for local and remote users are also included.

Hardware Maintenance

Includes all costs for vendor and third-party maintenance for all equipment owned or leased by the NAS Projects Office.

Software Licenses

Includes all vendor licensing costs for operating systems, libraries, test suites, storage, etc., used on NAS hardware.

User Services

Includes all costs associated with providing computational services to the user community, such as consultation, documentation and training.

Software Maintenance

Includes all costs associated with the maintenance and modification of vendor delivered or developed software and supports configuration management and testing of installed systems.

Management/Logistics

Includes all costs associated with the management of operational activities and provides computer related supplies and services.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

NOV 25 1985

Reply to Attn of C:MDD

Honorable Don Fuqua
Chairman
Committee on Science
and Technology
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

In the House Authorization Report 99-32, the Committee requested NASA submit to Congress a report on the joint NASA/DOD study of the space transportation needs of the United States.

I am forwarding the study in compliance with the Committee's request. Please call me if you have any additional questions concerning this matter.

Sincerely,

Jack Murphy

John F. Murphy
Assistant Administrator
for Legislative Affairs

cc:
Honorable Manuel Lujan, Jr.
Honorable Bill Nelson
Honorable Robert S. Walker

NATIONAL SPACE TRANSPORTATION AND SUPPORT STUDY

Introduction

The National Aeronautics and Space Administration and the Department of Defense are jointly undertaking a study of the development of a second generation space transportation and support system -- making use of manned and unmanned systems to meet the requirements of all users.

The purposes of the study are to prepare the United States to make important decisions regarding the second generation space transportation system and to revitalize the Nation's launch and logistics/support technology base. The principle end product of this study will be the identification of alternative launch vehicle technology developments deemed necessary or prudent for the post-1995 time period to meet United States space objectives.

The guiding principles of the study, as taken from U.S. space objectives, are:

- to satisfy the future needs of authorized users;
- to substantially reduce the costs of space operations to the government;
- to define a flexible and robust space transportation system; and
- to maintain world leadership in space transportation.

The study includes the following tasks:

- to compile a set of potential mission classes reflecting anticipated national security and civil government needs;
- to perform the necessary system analyses, trade studies and technology assessments to define the transportation and infrastructure options (manned and unmanned launch vehicles, transfer vehicles, and facilities) both on the ground and in space to satisfy the overlapping as well as independent portions of the two sets of potential missions;
- to identify the technologies that could be made available in the post-1995 period with emphasis on nonvehicle-specific technologies; and
- to define technology development programs prudent to support future vehicle development program decisions.

An additional task has been added to this effort to include the transition period between the launch of the last of the currently planned Expendable Launch Vehicles (ELV's) and the beginning of the second generation space transportation system study timeframe. This additional effort will identify any potential launch capability shortfall and identify any needed candidate solutions for this transition period.

The study organization and management structure is depicted in Figure 1. The study is being conducted by a joint DOD/NASA task team with a NASA co-Director and a DOD co-Director. Oversight of the study is being provided by a senior level joint steering group composed of an equal number of members from NASA and DOD. To properly reflect the cooperative spirit of this joint DOD/NASA activity, the management and direction of the industry contractors have been apportioned equally between DOD and NASA. Technical direction of the industry contractors is being closely coordinated to assure a common basis for the study effort.

Although the joint DOD/NASA task team will submit a report to the National Security Council in May 1986, the joint steering group and task team efforts will continue through completion of the 26 month industry contractor studies which were initiated in September 1985. Study milestones and schedules through completion of the report to the National Security Council (May 1985 - May 1986) are depicted in Figure 2.

Transition Task

(1992 - 1995)

The Joint Steering Group has directed the joint DOD/NASA Task Team to undertake an additional task to identify any potential launch capability shortfall during the 1992 - 1995 timeframe. This additional effort will include both capacity and assured access aspects and will identify candidate solutions to any launch capability shortfall. This transition task is being accomplished through government in-house efforts to assure that the longer-term architecture studies are not impacted with a near-term focus.

The most likely mission requirements will be identified including launch window, launch on need, and launch on demand considerations. This effort will be followed by an assessment of the ability of planned space transportation capacity to satisfy the most likely mission requirements in order to identify any launch capacity shortfall. Alternative solutions to satisfy any capacity shortfall and to provide assured access to space in the event an orbiter vehicle is out of service for an extended period of time will be identified and evaluated as part of this transition task.

National Space Transportation and Support Study

(1995 - 2010)

Scope. This Joint DOD/NASA Space Transportation and Support Study effort will address the total space transportation architecture to include its support systems and operational concepts. The study will assess mission requirements, perform architecture-level trade studies and analyses to determine the most cost effective philosophies for meeting projected mission and operational requirements, develop an architecture screening methodology, synthesize and screen space transportation architectures for the 1995 through 2010 period, define and cost the architectures, and perform architecture sensitivity and risk assessments. A preliminary operations and integrated logistics support plan shall also be developed for the defined architectures. For selected mid-1990's transportation and support systems concepts, the study will consider more detailed system/technology trade studies and analyses to refine the concepts, define the refined system concepts, prepare preliminary system plans, estimate system costs, and assess the growth potential and risks for the systems. As a major parallel effort to the above tasks, the study shall identify and assess the technologies needed for future space transportation architectures and prepare an integrated plan to develop technologies necessary for the most promising system architectures.

Requirements Assessment. Mission model and operational requirements will be defined for use as a common base in the architecture trade studies. The architecture studies will review and analyze the mission model and operational requirements/needs; define and prioritize system design or decision criteria; derive additional lower-tier transportation system requirements where needed to serve as a basis for concept formulation; and determine and assess any changes to the mission model and lower-tier transportation system requirements that result from the modularization and on-orbit assembly of large spacecraft.

Space Transportation Architecture Synthesis and Analyses. The space transportation architectures that can most cost effectively perform the total set of mission and operational requirements projected for the 1995 through 2010 time period (with consideration of the evolution of architectures into the post-2010 period) will be identified. A first iteration of the screening, trade studies, and definition portions of this task will be completed within the first six months of this study. The architecture synthesis will include architecture-level — operational trade studies and analyses in order to completely assess different possible operational and design philosophies (e.g., spacecraft servicing vs. replacement) and to establish the most cost effective overall operational concepts for the future space transportation systems. Utilizing operational concepts which are developed, the study will synthesize candidate architectures comprised of existing, modified, and new transportation systems and support elements; perform mission capture analyses to determine the possible mixes of launch vehicle and orbital transfer systems that can form space transportation systems to meet the different mission activity levels specified in the mission model; and determine the integrated logistics support and control systems required for the architectures. The architecture synthesis analyses will include an assessment of the following: spacecraft modularization and on-orbit assembly, on-orbit spacecraft servicing, space basing of systems, space platforms, reusability, and survivability.

Technology Assessment and Development Plan. The set of technologies will be identified for those future transportation architectures which best meet the system design or decision criteria. A development plan for these technologies will be developed. Specific consideration will be given to support technologies which can provide high leverage on system life-cycle costs and on nonvehicle-specific technologies. An integrated plan for cost effectively developing and applying the technologies identified will be developed, including technical approaches, goals, schedule, and costs for each major technology development task.

Study Phasing. During the first six months of the study, the first iteration of the architecture screening process will be completed. This iteration will provide: 1) a summary-level description of the most promising architectures for the complete 1995 through 2010 period, and 2) a preliminary development plan for the enabling and enhancing technologies for the architectures. A second iterative output shall be provided at the end of the first year. During the second year of the study, the system concepts for any near-term architecture will be refined. Updates to the technology development plan, the defined transportation architectures, and the post-2000 system concepts will also be made.

Summary. The guiding principles for this study are to satisfy the future needs of authorized users and to substantially reduce the costs of space operations to the Government. As such, innovative vehicle concepts and operational approaches which could significantly lower costs will be seriously pursued. Particular emphasis will be placed on streamlining, simplifying, and/or automating the relatively high cost vehicle ground processing tasks and the utilization of advanced, high-payoff technologies to reduce transportation costs.

STUDY ORGANIZATION

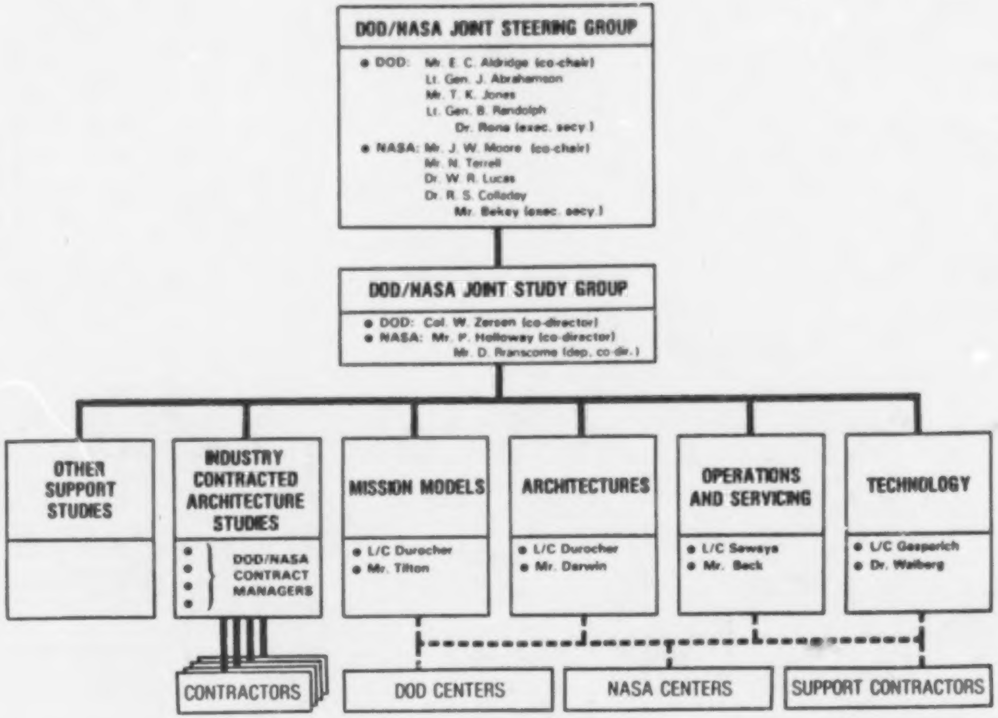
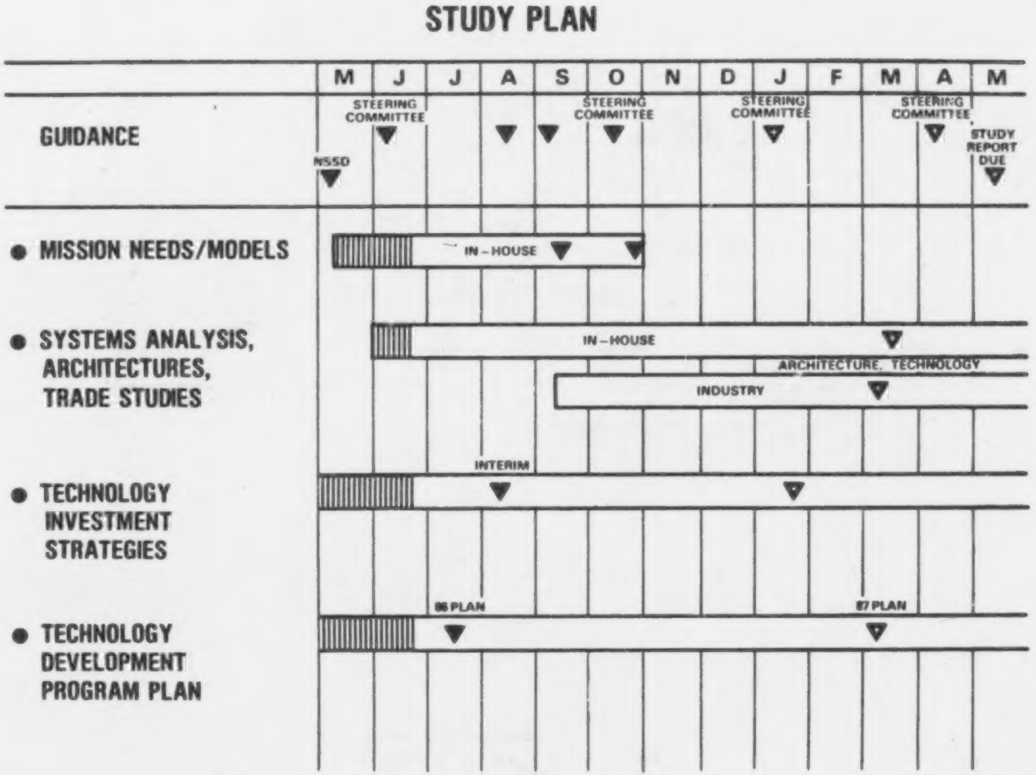

DOD/NASA JOINT STEERING GROUP
• DOD: Mr. E. C. Aldridge (co-chair)
Lt. Gen. J. Abrahamson
Mr. T. K. Jones
Lt. Gen. B. Randolph
Dr. Rona (exec. secy.)
• NASA: Mr. J. W. Moore (co-chair)
Mr. N. Terrell
Dr. W. R. Lucas
Dr. R. S. Colladay
Mr. Bekey (exec. secy.)
DOD/NASA JOINT STUDY GROUP
• DOD: Col. W. Zersen (co-director)
• NASA: Mr. P. Holloway (co-director)
Mr. D. Branscome (dep. co-dir.)
OTHER SUPPORT STUDIES
INDUSTRY CONTRACTED ARCHITECTURE STUDIES
DOD/NASA CONTRACT MANAGERS
CONTRACTORS
MISSION MODELS
• L/C Durocher
• Mr. Tilton
ARCHITECTURES
• L/C Durocher
• Mr. Darwin
OPERATIONS AND SERVICING
• L/C Sawaya
• Mr. Beck
TECHNOLOGY
• L/C Gasperich
• Dr. Walberg
DOD CENTERS
NASA CENTERS
SUPPORT CONTRACTORS

Figure 1

MT-85-146



STUDY PLAN

Figure 2

MT-85-142
10/23/85

NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546

DEC 9 1985

Reply to Attn of C:LH:brb

Honorable Don Fuqua
Chairman
Committee on Science
and Technology
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

As you know, NASA and DOD have been working together for some time to establish a fair and equitable pricing policy for DOD use of the National Space Transportation System in the post FY 1988 time frame, covering the period FY 1989 through FY 1991.

We are pleased to advise you that we have reached agreement on that policy.

Based on the careful work of our respective staffs, and following several useful meetings between us, we have agreed to the price of $60 million in FY 1982 dollars as the fair and proper price for the pricing period FY 1989 through FY 1991. This price is based upon the estimated cost to fly and an exchange of services between DOD and NASA. The price will be divided into a fixed base in the amount of $30 million for each flight planned and, for each flight actually flown, an increment amount of $30 million.

DOD will pay a base amount of $270 million (FY 1982 dollars) each year. (This is based on a planning assumption of nine flights per year, although DOD will pay the same fixed charge, regardless of the number of flights actually flown). For each flight actually flown, including those above nine, there would be an additional charge of $30 million. By combining a significant fixed charge ($270 million) with a low variable cost ($30 million per flight), the agreement ensures that NASA will be able to cover its costs while giving DOD a strong incentive to use the Shuttle to meet its needs.

A copy of the NASA/DOD PRICING AGREEMENT, PHASE III, FY 1989 through FY 1991 is enclosed for your information. We are confident that this agreement will be in the best interest of our respective agencies and will result in the most efficient use of the National Space Transportation System.

Staff personnel will be available to provide further information.

Sincerely,

Jesse W. Moore
Associate Administrator
for Space Flight

Edward C. Aldrige, Jr.
Under Secretary
of the Air Force

cc: Honorable Manuel Lujan

NASA/DoD PRICING AGREEMENT, PHASE III, FY 1989 THROUGH FY 1991

This is to document our agreements regarding the DoD price for standard services on STS flights for the Phase III pricing period. This Phase III price is based on certain firm principles:

1. DoD funds will be used only for support of DoD missions, and not to provide a subsidy to non-DoD flights.

2. DoD guarantees that it will commit to a minimum of one-third of the available flights, nominally eight equivalent flights per year.

3. This agreement recognizes the contribution that the DoD is making to the operation of the National Space Transportation System.

4. The reimbursement plan for the Phase III period will be structured such that the DoD is incentivized to use the National Space Transportation System as called for in NSDD 164.

Based on these principles, it is hereby agreed that:

1. This agreement is made with the understanding that launch services and range support services at the Kennedy and Vandenberg launch sites for the baseline capability will be exchanged on a quid pro quo basis between NASA and DoD with neither agency charging the other for such services.

2. The DoD price for STS flights will be \$60M in FY 82\$ (\$75M in FY 86\$) throughout the Phase III pricing period, that is, for flights during the period FY 1989 through FY 1991.

3. This price of \$60M will be divided into a fixed-base increment in the amount of \$30M and a marginal increment in the amount of \$30M. The total fixed-base increment per year will be determined by the number of STS equivalent flights planned per year during Phase III times \$30M. The marginal increment of \$30M will be paid for each flight actually flown. Throughout the Phase III pricing period, the fixed base flight rate will be set at nine equivalent flights per year (under the assumption of 24 flights per year for the orbiter fleet) thereby setting the annual fixed-base portion of the price at \$270M in FY 82\$ (\$338M in FY 86\$).

4. DoD payment will be made to NASA no later than January of the fiscal year prior to the fiscal year of flight. Each year, the DoD payment will include a fixed-base in the amount of \$270M plus the total amount of the marginal increment for the total number of flights actually planned for the year as specified in the DoD STS annual commitment letter.

5. DoD will pay the added cost of filament wound case (FWC) used by the Shuttle at VAFB (after the initial six-flight sets which will be provided by NASA), provided no other performance enhancements will satisfy the primary mission objectives. If FWC are added to provide performance over and above that required to satisfy the DoD primary mission, then the agency responsible for payment shall be determined by DoD and NASA jointly.

6. It is further agreed that the DoD will be a full participant in making the joint determination that a filament wound case is required on any given mission. This determination will be documented in the DoD commitment letter to NASA each year. Moreover, a separate DoD/NASA Memorandum of Agreement regarding the establishment of requirements criteria, price, and availability of the FWC will be completed by January 1986.

Edward C. Aldridge Jr.
Under Secretary of the Air Force
November 27, 1985

Jesse W. Moore
Associate Administrator for Space Flight
NASA
November 27, 1985

AEROSPACE
SAFETY ADVISORY PANEL

ANNUAL REPORT

COVERING CALENDAR YEAR 1985

JANUARY 1986

The Aerospace Safety Advisory Panel shares in the nation's grief over the loss of the Space Shuttle Challenger and its heroic crew. Despite this, the Panel believes it is essential for NASA to continue its manned space flight program. The Findings and Recommendations of this annual report were completed prior to the January 28th accident.

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I. EXECUTIVE SUMMARY

The level of activity of the Aerospace Safety Advisory Panel was increased somewhat during 1985 in concert with the increased mission rate of the National Space Transportation System, the evolutionary changes in management and operation of that program, and the preparation of the Vandenberg Launch Site; the implementation of the Program Definition Phase of the Space Station Program; and actual flight testing of the X-29 research aircraft. The Panel continued its review of impending unique payload STS missions and NASA's overall aircraft operations. The Panel also responded to a request by the NASA Administrator to assess the safety aspects of the Leasat salvage mission.

This report summarizes the Panel's 1985 work, and enumerates its findings and recommendations for the attention of NASA management. NASA's response to the Panel's 1984 report findings and recommendations is appended hereto (ref. Appendix E).

The Panel wishes to note its appreciation for the continuing excellent support of all government and industry entities contacted, thus enabling the Panel to perform its statutory responsibilities.

Panel Meetings

The full Panel or Panel members conducted 54 fact finding sessions during calendar 1985. Meetings were held at NASA Headquarters, seven NASA Centers, six contractor sites, Vandenberg Air Force Base, and three other locations. In addition, the Panel presented testimony before the U.S. House of Representatives and U.S. Senate, and held other discussions with congressional staff.

Space Transportation System (STS)

The STS performed in a highly credible manner during 1985. It was a period of continuing transition to increased launch frequency, while, at the same time, undergoing a number of organizational and operational responsibility changes (which included numerous key personnel changes). The program team (government and industry) demonstrated its capability to successfully deal with real-time anomalies to plans, and its flexibility to revise, implement, and execute new plans and schedules to accommodate the anomalies. An outstanding example of this was the Leasat salvage mission. Given the operational system complexities and the sheer magnitude of effort required to safely execute each STS mission, the Program achievements during 1985 were, indeed, noteworthy.

Attainment of NASA's goal of 24 STS launches per year remains sometime in the future, challenging the capacities of both physical and human resources. While plans are being implemented to provide the necessary balance of resources, the goal is all the more challenging considering that: (1) a number of flight hardware components are still undergoing development for both performance and reliability; (2) additional "brick and mortar" facilities are required at KSC for orbiter processing and component maintenance; (3) there are ultimate limitations of human resources to compensate for shortfalls in the physical resources (even with extraordinary dedication and effort); (4) sufficient logistics support, in both hardware and systems, lies sometime in the future; and (5) the fact that all of the above are subject to constraints by budgetary allocations. Nevertheless, the Panel believes that a safe and productive STS Program can be carried out if the System's real state-of-the-art and other limitations are recognized and integrated into the program planning and scheduling.

Several elements of the STS are discussed under Section II and expanded upon under Section IV of this report. One which the Panel wishes to note in this section is the uncertainty of the structural strength of the Filament Wound Case (FWC) for the Solid Rocket Boosters (SRBs). Tests and analyses to date leave considerable question as to the strength margins of safety in the transition areas between case segments. Until the issue can be resolved with a high level of confidence, the Panel believes the FWC SRBs should not be used for STS launch (and certainly not for first launch from VLS). A great deal of attention is being given to the issue, including a select committee of the most knowledgeable experts available.

The Panel also wishes to note its support of the NASA/Air Force decision to reschedule the first STS launch from the Vandenberg Launch Site (VLS) until after mid 1986. Good progress is being made in bringing the VLS on-line and the additional time to complete the process will provide for orderly checkout and confirmation of launch readiness for both the site facility and the launch team.

STS - Payload Related Issues

There do not seem to be many payload-related safety issues arising. This would say that all the time and effort spent on payload planning has been well spent and while the system at first glance seems formidable, it is entirely workable as many payloads have proven. The exceptional performance of the astronauts in space in payload emergencies is such that this factor should be recognized in the design of payloads, with for instance, the accessibility to a suited crewman of critical parts of the payload. It also points up the continuing need for a more flexible space suit or alternatively an end-of-arm manipulator to perform the normal hand functions--perhaps both.

Shuttle - Centaur

The Centaur payload is a special case. The Centaur is a complex, massive machine using cryogenic fuel, originally designed for unmanned launch and with a long successful history. The hazards--particularly in an abort situation--of the Centaur to the Shuttle are such that it must be integrated with the Shuttle, rather than being just a payload. This has been a long hard task but seems to be well underway. The remaining problems do not seem to be technical but rather schedule.

Radioisotope Thermal Generator (RTG)

The deployment into space of an RTG requires specific Presidential authorization before launch. There is a mechanism set up to accomplish the risk assessment and in the past the necessary launch permission has been granted. Except for some of the manned abort scenarios, there are no substantially greater risks with the Shuttle Centaur than with previous unmanned launches, both solid and liquid fueled, carrying RTGs in the payload. We do not see an undue safety concern in the use of an RTG on the upcoming Shuttle Centaur flights, in light of the reviews, attention, and consideration that have been given this issue.

Space Station

The Panel continued to monitor the Space Station Program organization, planning, and "Phase B" (program definition and system preliminary design) through 1985. A broadly based effort is well under way, involving NASA Headquarters, four NASA Centers (each with line responsibility), the full spectrum of U.S. aerospace industry in competitive and support roles, and several international partners. Both the program goals and the broad institutional involvement in program execution create very challenging management requirements. The panel foresees management/organizational concepts and arrangements, consistent funding support, and judicious funding allocation as being the key factors in successfully achieving the President's objectives for the Space Station Program. The technologies needed to, produce and deploy the Space Station are essentially in-hand (relatively little "new technology" is required compared to the STS Program).

The Panel will continue to monitor the program developments, principally with regard to the resulting effects on system safety. Some of the Panel's current considerations are discussed in Section IV.

Space Junk

The safety concern caused by the presence in space of debris from past launches and satellites is growing but is difficult to characterize, except statistically. This "space junk issue" can only be resolved by international cooperation and action, and such a solution is slow. Efforts to resolve this issue internationally must be intensified before it moves from the concern to the problem condition. Any solution must consider not only the large trackable units but the small debris that represents an unavoidable collision hazard. The Panel would urge NASA through appropriate channels to establish an international consideration of this issue before it becomes a critical problem.

Research Aircraft Programs

State-of-the Art extensions in Aeronautics are being undertaken in the experimental aircraft programs, such as the X-29 (forward swept wing) and X-Wing Rotor Systems Research Aircraft. Panel members with expertise in the related technologies and experimental flight programs are active in program safety assessments. To date the Panel is satisfied that appropriate safety initiatives are proving to be effective. Both programs involve new techologies and complex control systems, with attendant risks, and require a high level of on-going safety emphasis.

NASA Aircraft Operations

While the Intercenter Aircraft Operations Panel continues preparation of operations guideline documents, a void still exists at NASA Headquarters in appointing a qualified management level individual to head up the Aircraft Management Office. The ASAP believes strongly that agency-wide operations and maintenance standards should be established under Headquarters authority and administered through the leadership of an operations qualified manager or director.

II. FINDINGS AND RECOMMENDATIONS

A. Space Transportation System (STS)

1. Orbiter Structural Life Certification

Findings

The wing root fatigue analysis and fracture analysis certification report funding has been stopped without completion of the documentation.

Recommendations

An abbreviated conservative analysis should be documented to fulfill the certification program.

2. Orbiter Structural Adequacy: "ASKA 6" Loads/Stress Cycle Program

Findings

Due to the latest flight test results, an arbitrary "collector force" (a force simulating stresses at critical wing locations) will be added to the wing loads which will be used in the final 6.0 loads/stress program. Rockwell will also have to complete the final analysis within an allocated budget and time frame.

Recommendations

The Panel agrees with the arbitrary force approach taken at this time. However, the primary load path structure and thermal protection system analysis should be a stand alone report fully documented and referenced even if the 9/30/87 end date slips. In addition, it is felt that an operating restriction report and strength summary (external loads and vehicle stress) report for each orbiter should be prepared in order to have quick access to information for making future decisions.

3. Redlines and Modifications

Findings

Loads analysis from Orbiter capability assessment - Cycle "D" (OCA - D) and "collector load" concept require wing mods (MOD I, II & III, see section IV.D.1.a) on all vehicles.

Recommendations

In order to provide 85% launch probability redlines, the modifications should be made, even if slightly conservative, in some structural areas. Redlines on OV - 103 and OV - 104 should be specifically examined and changed as required.

4. Orbiter Avionics and Software

Findings

Although we have been assured that no changes will be required in the applications software for the new, uprated general purpose computers (GPCs), there remains a nagging concern that this might not be the case. The new computer has new codes and the temptation will be great to use them to "improve" the applications software. To discourage this human foible, the software compiler will not recognize the new codes. For meeting the logistics associated with these new computers the plan is to buy one new computer each year after the initial purchase.

Recommendations

NASA must monitor this most carefully since applications software can be very expensive to change and retest. Discipline with regard to the new computer codes may be more difficult to implement than management thinks...it was tried on the Apollo program with little or no success. The wisdom of procuring one new computer each year may well lead to the same problem with spares found throughout the LRU program, and deserves additional attention, especially with increasing flight rate and the use of "new" computers.

5. Brakes and Nose Wheel Steering

Findings

The STS program has made a great deal of progress in alleviating the brake problems found on nearly all of the first 21 flights. With the activation of nose wheel steering capability, there has been a marked lessening of brake damage during subsequent landings. The decision to proceed with development of the structural carbon brake, and possibly use a fifth rotor to replace the current beryllium rotors and stators, has been made.

Recommendations

Standard use of nose wheel steering is recommended, regardless of the type of brakes. The system performance should also be analyzed to permit increasing nose wheel steering authority as much as practicable in order to maximize crosswind landing capability. The carbon brake design should be pursued as quickly as possible to replace current materials. The resulting configuration should provide manifold improvement in Orbiter landing ground roll control and stopping reliability. Further, the Panel is still hopeful that NASA will seek practical means of reducing Orbiter landing speed.

6. Flight Crew Training

Findings

The Orbiter landing is a critical phase of each STS mission. Flying qualities of the Orbiter are unique due to its configuration, compounding the demands upon the flight crews at this critical time. NASA has recognized this and met the requirements by assignment of skilled pilots who receive extensive hands-on training in ground simulators and Orbiter flight simulator aircraft. The increasing STS mission rate demands an attendant increase in flight crew training. The time available in the present fleet of Orbiter flight simulator aircraft is becoming marginal and can be foreseen as being inadequate to meet future training demands.

Recommendations

NASA must commit the funds in a timely manner to ensure an adequately-sized fleet of training aircraft to meet the flight crew training needs, without reduction or compromise to the Orbiter flight training syllabus.

7. Space Shuttle Main Engines (SSMEs)

Findings

In 1983, a three-phase program was initiated to substantially improve the SSME. However, as a result of severe funding-rate limitations, the program was restructured in 1984 to address only certain improvements to the wear life of various turbopump components (Phase II), plus a limited effort on development of a new hot-gas manifold (Phase II+). Most of the turbopump component improvement work has gone very well during 1985, and these new components will be incorporated into a two-engine Phase II recertification program. This "certification" is planned to demonstrate that the non-turbopump components of the engines are capable of 20 missions (with 40% operation at 109% of rated thrust), and that the high-pressure turbopumps are capable of 5 missions. A three-engine main propulsion-system test (MPT) is scheduled to be performed to assure there are no feed-system interaction problems at 109% operation. The Panel strongly supports this system test as being highly desirable.

. The new powerhead manifold will be incorporated in a later demonstration program in 1986, but at the present time there is no approved plan to demonstrate the large-throat combustion chamber, which is necessary to really improve significantly the turbopump operating environments at 109% thrust.

Recommendations

The recertification approach selected by NASA permits different parts of the engine to be "certified" for different flight times. However, since most of the Phase II turbopump component improvements really only address degradation rates of critical components under nominal mission environments rather than increased stress level margins (the exceptions are the decreased High Pressure Fuel Turbine discharge temperatures $\sim 100^{\circ}$ and a 7000 RPM improvement in synchronous whirl margin on the oxidizer turbopump), the Panel recommends that the engine be operated at power levels above 104% of rated power only when mandatory. Also, when engine operation above 104% is necessary, the power level selected be only the value required for the particular mission and not taken all the way to 109% except when mandatory.

The Phase II development and demonstration program should provide a data base for the modified turbopumps which can be used to estimate new Mean-Time-Before-Replacement criteria for the turbo-machinery. The hardware necessary to support this replacement rate should be made available in order to maintain the engine's new certification status and protect flight safety margins.

We further recommend that the "precursor" (future) program improvements be supported at a level such that they can in fact be incorporated as soon as possible into the flight engines. In the long run, such expenditures will be cost effective as they result in more reliable flight engines with lower maintenance costs and a higher availability factor.

8. Solid Rocket Boosters

Findings

The effect of the new launch mount and the filament wound motor case flexibility has been assessed by "Cycle III" loads analysis and found to be similar to the previous calculated "Cycle II-B" loads which gives added confidence to predictions made to date. However, the hold down Solid Rocket Booster calibration confirmation tests will not be available until late Spring of 1986.

Recommendations

The Solid Rocket Booster hold-down bolt calibration tests should be carefully examined at this time to aid in obtaining meaningful final test results. If the calibrated test results differ from that used in the Cycle-III analysis then the prelaunch and lift-off loads for the External Tank and Solid Rocket Booster will be incorrect. This could cause serious problems in meeting launch requirements.

Findings

The filament wound case test article, STA-2, was tested and prematurely failed. However, there were process and design differences between STA-2 and the VLS-1 flight article. The follow-on test STA-2B will be tested to 140% of limit load using a design comparable to the flight test article. Additional full-scale pressure and compression tests are being made to certify the filament wound case design. There is a heavy dependence on analysis and modifications based on a very limited hardware base and a set of design changes resulting from test failures.

Recommendations

Continued analysis and further studies have to be conducted in order to fully understand the failure mode. Additional studies should continue to evaluate membrane/transition lay-ups and coupon specimens. Until the issue can be resolved with a high level of confidence, the Panel believes the FWC SRBs should not be used for STS launch. The Panel would like to be kept informed of the analysis results and of these upcoming tests.

9. Logistics and Launch Processing

Findings

The Shuttle Processing Contractor (SPC), while not yet at its peak, has laid the organizational groundwork and obtained the right sort of personnel during the year. A general assessment indicates very satisfactory progress is being made.

Launch rate predictions are still very optimistic in the light of Space Shuttle Main Engine developmental and spares problems, spares shortages of line replaceable units, excessive modification workload, etc. For the next 2 to 3 years, 12 to 15 flights per year appears to be a difficult but attainable goal.

Arrangements for transfer of functions such as sustaining engineering, logistics management, etc., from JSC to KSC seem to be well organized and an orderly, if somewhat slow, transition should eventually result.

Overall safety practices and monitoring systems--especially by the SPC--at KSC are praiseworthy and would appear to do everything reasonable to ensure the safety of operating personnel.

Recommendations

a. NASA management should monitor closely the effects of the recent reorganization at KSC to make sure that it has accelerated and simplified management of launch processing.

b. NASA should examine the feasibility of developing data systems under management of the SPC, such as configuration management, that will centralize and augment KSC's operational launch capability.

c. NASA should continue to give high priority to acquisition of spare parts and to upgrade the reliability (planned life) of hardware, especially items associated with the space shuttle main engine.

d. NASA should explore whether better coordination could be achieved between those persons determining manifests for specific flights and those persons charged with launch processing. In some instances, the combination of payloads has exacerbated the launch processing sequence.

e. Facilities should be provided to minimize turnaround times of the Shuttle and Line Replaceable Units (LRUs).

- o Orbiter Maintenance and Refurbishment Facility (OMRF) building should be authorized.
- o LRU repair facilities should be provided at KSC for all units which can be properly and efficiently handled there.

B. Payload Interface Standardization

Findings

Shuttle turnaround times remain in the forefront of planning for future STS flights. One of the significant factors that affects turnaround-times is the lack of interface standardization among the various payloads carried into orbit. A considerable effort has been expended in the area of standardization and the prime example is the PAM.

Recommendations

There will always be peculiar requirements for special payloads, but insofar as is feasible, there should be increasing effort to preparing and carrying payloads in a standardized fashion.

C. Extravehicular Activities (EVA)/Space Suits

Findings

This year's activities show that EVA will continue to be in extensive use. The Leasat rescue mission is an outstanding example of its use during the past year. Certainly the Space Station will require extensive EVA for its construction and for its operational activities. The current suit continues to function well, despite its limitations. The need remains for a more flexible suit that has the capability of operating at a higher pressure than the current suit.

Recommendations

NASA should continue to support the development of a more flexible, higher pressure EVA suit and fund the development in an appropriate manner.

D. Space Station

Findings

The Space Station organizational structure is quite complex, with roles and responsibilities difficult to discern at times. The system is maturing, while there remains some questions concerning NASA's ability to adequately handle the systems engineering and complete integration of Phases C & D, the hardware and software development and implementation. Integrating a large development effort, such as the Space Transportation System, has been accomplished through an integrating contractor and supporting contractors and NASA has not performed a full integration role before.

Recommendations

NASA should re-examine the resources required to conduct the many facets of the Space Station integration effort to ensure that the organization and human resources are sufficient to properly fill this role, now and in the future.

Findings

The Space Station exists in an essentially benign environment once on orbit when compared to the ascent conditions within the Orbiter payload bay.

Recommendations

NASA should determine possible means to alleviate the payload bay interface environment and design requirements (vibration, accelerations, loads) which drive some of the Space Station element and "user" designs.

Findings

"Build-to-cost" management for the Space Station may involve many of the same or similar activities that confronted the Space Shuttle in its formative days. Looking into such shuttle management and technical activities, and the resultant decisions, could provide Space Station management with an understanding of possible pitfalls to avoid, if not many positive directions to take, thereby preventing inefficiencies in the use of available resources.

Recommendations

NASA should establish a small team composed of current and retired NASA/contractor persons who have first-hand knowledge of the early activities (1972-1976) on the Space Shuttle program. The team should define the "lessons" that can be "learned" in both management and technical areas, including the real possibility of using today's technology to meet Space Station needs.

E. Aircraft Operations

Findings

There is still no head of the NASA Headquarters's Aircraft Management Office. This precludes proper focusing of management's attention upon achieving centralized aircraft operational control. Agency-wide flight operations and maintenance policy and guidelines documents to be used by both Headquarters and the NASA Centers have been slow in being issued.

Recommendations

NASA should appoint, as soon as possible, a qualified operations manager as head of the Aircraft Management Office. Determine methods to reduce the time it takes to obtain review and approval for critical flight operations guidelines and policies which are generated at Headquarters.

III. PANEL PLAN FOR CALENDAR YEAR 1986

Panel Membership

The Panel selected a new member, Dr. Harold M. Agnew, to fill the vacancy which occurred when Herbert E. Grier retired from the Panel. Mr. Grier remains with the Panel as a consultant. Dr. Agnew's experience in managing high risk, high visibility national programs will be of great value to the Panel as it delves deeper into the Space Station Program.

Dr. Harold M. Agnew has been in the forefront of nuclear energy development since the early 1940s. In 1979, he joined General Atomic Company, after serving as Director of the Los Alamos Scientific Laboratory in New Mexico. He retired as President from General Atomic Company on December 31, 1984. Dr. Agnew is, among many other achievements, a Fellow of the American Physical Society and a Fellow of the American Association for the Advancement of Science.

Dr. Norris J. Krone, Jr. has been working with the Panel as a consultant in the fields of aeronautics and structures, particularly with regard to the X-29A and the X-Wing research and development projects which NASA has been working with DARPA. Dr. Krone, a recognized expert in his fields, is currently Executive Director of the University of Maryland Research Foundation.

Panel Activities for 1986

The Panel's areas of interest are those which further NASA program/project technical goals and reduce adverse events associated with meeting those goals. Specifically, one divides such activities into "on-going" and "new" areas of interest.

A. On-Going

1. X-29A Phase II supersonic flight envelope expansion, including maintenance and logistics support, flight test plans, and crew training.

2. X-Wing Rotor Systems Research Aircraft flight readiness process, including software validation, component fatigue tests, powered model testing, and other certification activities.

3. Space Transportation System, with regard to the transition of activities from development Centers and contractors to KSC operators. Safety assurance under conditions of budget reductions and increased flight rate.

4. Space Station, as it moves through Phase B into the development and construction (Phase C & D). Panel effectiveness depends upon early input.

5. A number of supporting areas, such as life sciences, human factors, Extra Vehicular Activities, Aircraft operations, ground support equipment and facilities, and payload interfaces.

B. New

1. Oblique wing research aircraft project.

2. Tether satellite project, as it interfaces with the Orbiter.

3. Orbiter "Heads-Up" ascent mode of flight, attempting to gain additional payload capability.

4. Space debris, as it affects STS and Space Station activities.

5. Safety impacts of any reduction of payload requirements for those who fly on the Shuttle.

6. Hazardous Material Identification and Material Safety Data as required by statute, and its effect on NASA operations.

7. Transfer of appropriate knowledge from outside into NASA programs to enhance safety, reliability, and maintenance applied to a maturing Space Transportation System, and the buildup of the Space Station.

8. Space Station Orbital Transfer Vehicle interfaces and impacts.

9. Orbiter landing/arresting systems to preclude loss of Orbiters due to landing site overruns or side runs.

As requested, the Panel will respond to NASA management and the Congress regarding safety of NASA activities with due regard to public safety at all times.

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IV. APPENDICES

A. PANEL MEMBERSHIP/CONSULTANTS/STAFF

John C. Brizendine (Chairman)
Aerospace Consultant
President of Douglas Aircraft Company (Retired)

Harold M. Agnew
President of General Atomic (Retired)
Director, Los Alamos Labs (Retired)

Richard H. Battin
Associate Department Head
Charles Stark Draper Labs

Charles J. Donlan
Institute for Defense Analysis
Consultant

Gerard W. Elverum, Jr.
V-P/Gen. Mgr, Applied Technology Group
TRW Space and Technology Group

John F. McDonald
Aeronautical Consultant
V-P Maintenance & Engineering
TigerAir, Inc. (Retired)

John G. Stewart
Assistant General Manager, TVA

Melvin Stone
Director of Structural Mechanics, DAC (Retired)
Aeronautical Consultant

Norman R. Parmet
Aeronautical Consultant
V-P Engineering and Quality Assurance
TWA (Retired)

Panel Consultants

Herbert E. Grier
Senior V-P, EGG, Inc (Retired)
Consultant

John P. Reeder
NACA/NASA Chief Research Pilot (LaRC)
Consultant (Retired)

Seymour C. Himmel
Associate Director, NASA Lewis
Research Center (Retired)
Consultant

Norris J. Krone, Jr.
Executive Director
University of Md Research Foundation

Ex-Officio Member

Milton A. Silveira
NASA
Chief Engineer

Staff

Gilbert L. Roth
NASA
Staff Director

B. AEROSPACE SAFETY ADVISORY PANEL

ACTIVITIES CY 1985

DATE	SITE	PERSONNEL	SUBJECT
1/23	Chicago	Parmet	Life Sciences Planning Group
1/18	NASA Hqs	Himmel	Space Shuttle Main Engine
1/29-30	LaRC	Donlan	Orbiter Upgrade (Canards, etc.)
1/31	NASA Hqs	Reeder	X-29A and X-Wing Safety
2/14	NASA Hqs	All	Annual Meeting
2/20	Congress	All	House of Representatives Hearing
2/25-26	Sikorski	Krone, Reeder	X-Wing Review
2/25-27	PAFB, FL	Parmet	NASA Intercenter Aircraft Panel
3/4	ARC	Donlan	STS Studies, Crew Training
3/7	DFRF	Reeder, Donlan, Parmet	X-29 Safety Review, R&D Operation
3/20	JSC	Battin	STS Computers/MDMs/Software
4/2-3	MSFC	All	STS Projects & Special Projects
4/4	NASA Hqs	Roth	STS 51D FRR Telecon

4/16-18	Gen Dyn, CA	Grier	Phase II Centaur Safety Review
4/16-19	DFRF	Krone	X-29A Activities
4/23-25	Columbia, TX	McDonald	Space Station Special Task Team
4/17	RI/Downey, CA	Stone	Orbiter Structure Adequacy
4/24	Sundstrand, IL	Parmet	Current/Improved Orbiter APUs
5/9-10	KSC	Stewart, Parmet	SPC Operations for STS
5/29	KSC	Parmet	Intercenter Aircraft Ops Panel
5/30	JSC	Grier, Himmel, Donlan, Parmet	STS 51-I Leasat Salvage Mission Special Review Team
6/4	Gen Dyn, CA	All	Shuttle/Centaur Mission Safety
6/5	RI/Downey, CA	All	Shuttle/Centaur, Orbiter
6/6	Rocketdyne, CA	Elverum, Himmel, Donlan, Elms, Williams	SSME Status (Phase II,II+ et al)
6/6	Hughes, CA	Brizendine, Grier, Himmel, Donlan, Parmet, Elms, Williams	STS 51-I Syncom Salvage Mission

6/7	VAFB, CA	Parmet	VAFB Activation
6/19-20	JSC	Grier, Parmet, Elms, Williams	STS 51-I Syncom Salvage Mission
6/19-20	VAFB, CA	McDonald	STS System Safety Panel
7/1	Thiokol, UT	Himmel	Accident Investigation Team
7/1	ARC	Reeder, Krone	X-Wing Safety Review
7/2	DFRF	Reeder	X-29A Review
7/18-19	NASA Hqs	Parmet	Life Sciences Advisory Committee
7/22-26	ARC et al	Parmet	Convair 990 Investigation Team
7/30-31	JSC	Parmet, Grier	STS 51-I Salvage Mission
8/1	MSFC	Elverum, Himmel	SSME Ad Hoc Review Team
8/16	NASA Hqs	Elverum, Himmel	SSME Ad Hoc Review Team
8/15	NASA Hqs	Himmel	STS 51-I Flight Readiness Review
8/20	NASA Hqs	Himmel	Propellant Accident Team Report
9/10-11	JSC	All	Space Station, Special STS Topics
9/12	JSC	Parmet, McDonald	STS Safety, Quality Assurance

9/17-19	ARC, DFRF	Reeder	X-29 Activities
9/24-25	KSC	Roth	Level I Centaur Management Review
10/2-4	Sikorski	Krone	X-Wing Safety
10/9-10	KSC	Stewart, Parmet, McDonald	STS Operations en toto, JSC to KSC Transition, KSC/VAFB Efforts
10/23	NASA Hqs	Roth	STS 61A Nose Wheel Steering
10/28-30	JSC	Reeder	Orbiter Concerns, Space Station
10/29-31	TWA, KS	Parmet, Roth	Intercenter Aircraft Ops Panel
11/19	Rocketdyne, CA	Elverum, Himmel	SSME Update
11/19-21	LaRC	Parmet	Aircraft Ops Safety Review Team
11/20-21	Gen Dyn,CA	Grier, Himmel	Centaur Design Certification Rev.
11/21	NASA Hqs	Brizendine, Donlan	Space Station Management Review
11/22	VAFB, CA	McDonald	Level I Design Cert. Review
12/4-5	VAFB, CA	All	Shuttle Operations - USAF
12/10	MSFC	Elverum	SRB/FWC, SSME,Composites
12/11	NASA Hqs	Roth	STS 61-C FRR
12/19	RI/Downey, CA	Stone	Orbiter Systems Update

PANEL REPORT ON SYNCOM SALVAGE MISSION

NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546

June 28, 1985

Reply to Attn of: LB/GLR

TO: A/Administrator
M/Associate Administrator for Space Flight

FROM: LB/Staff Director, Aerospace Safety Advisory Panel

SUBJECT: Safety Assessment of the Leasat/Syncom Salvage Mission (STS 51-I)

INTRODUCTION

The Aerospace Safety Advisory Panel was requested to assess the safety of the plans and implementation to salvage the Leasat/Syncom now in orbit on the STS 51-I mission. A preliminary assessment was provided by memo dated June 11, 1985. This report is the Panel's final assessment. There may be further comments as a result of the upcoming mission operations certification review scheduled for July 30-Aug 1 at JSC.

The Panel team included Norm Parmet, Herb Grier, Charlie Donlan, Sey Himmel and Gil Roth with support from Walt Williams and Jim Elms. The following activities were conducted:

May 30	JSC	Hazard analyses, EVA, handling hardware, interfaces
Jun 5	Rockwell	Orbiter operations
Jun 6	Hughes	Leasat failure cause, vehicle state, salvage safety
Jun 19-20	JSC	Phase III Safety Review, hardware DCR

This was, by necessity, a limited review with the objective of ascertaining the adequacy of salvage mission management, Leasat status now and at the time of the mission, hardware design, crew operations, mission rules, risk analyses as they all affect mission safety.

ASSESSMENT

Safety first then mission success are the priorities for the salvage operation. Both NASA and Hughes have explored and reviewed the salvage task thoroughly and appear to have practical and safe plans for its implementation. Mission simulations at both JSC and Hughes facilities have been and continue to be conducted to replicate each task and step to be taken, including contingency modes. To date there is nothing that represents a source of significant concern with regard to safety. It should be safe to proceed with the mission assuming nothing negative arises from the final reviews to affect the safe operation as we see it now.

We would like to re-emphasize the following: (1) mission rules, now in work, must be clear, concise and complete to assure such things as proper checkout of the many electronic boxes in the cabin and no EVA missteps, (2) assure overlap of JSC and Hughes activities so that nothing can drop-through-the-crack. The continuing working group meetings and reviews should assure this, (3) the spacecraft attitude, spin rate and internal state are not fully known, therefore, analyses of these conditions must continue so that their affects on the mission can be factored into the plans and implementation, (4) if the adverse tolerance buildup theory for failure of the Leasat is correct, it illustrates once again how little things can be the cause of major problems, therefore, no matter how simple or mundane a thing is it can not be overlooked.

FAILURE MECHANISM

Having proved by the STS 51-D "flyswatter" operation that the most probable single point failure probably did not cause the Leasat malfunction, Hughes looked carefully into multiple failure scenarios. By analysis and test they found that a dual failure of the Perigee Kick Motor (PKM) separation switches was the most credible failure due to a design deficiency caused by structure warpage and insufficient switch plunger length, see attached figure. In this case the Post Ejection Sequencer (PES) would never be powered. The proposed salvage operation is based on working around the PKM separation switches and providing inhibits and allowing for ground control (not internal spacecraft) of spacecraft activation.

SAFETY AND MISSION SUPPORT ACTIVITIES

The salvage activities make use of JSC and Hughes designed and built equipment to meet specific demands of Leasat handling and attitude control, vehicle safing, internal system modification, and redeploy. The original STS payload safety requirements based on NASA's NHB 1700.7A were provided and approved December 1983. These requirements have been reexamined and updated June 14, 1985 to meet the salvage mission requirements. Items considered "open" because they are still in work and will be completed by the end of July 1985 are: Hardware Picture Book, Details of Cabin Checkout Box, In-Cabin Checkout Procedures, EVA Operational Procedures, and Completion of Unit and System Test Program.

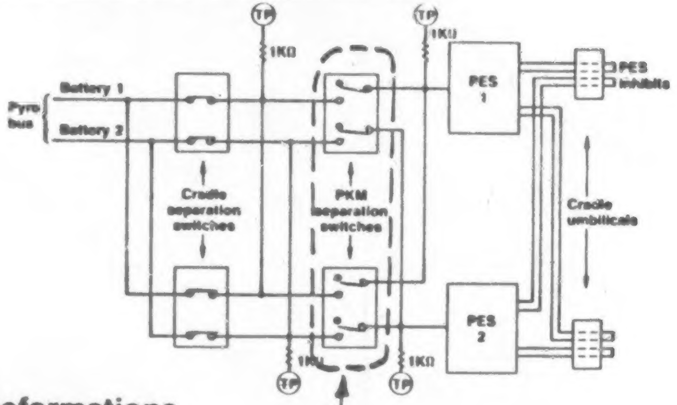
JSC developed procedures for the mission, EVA equipment, crew training and interfacing with Hughes show a thorough understanding of crew/orbiter safety needs. Crew training in 1g and neutral buoyancy facilities at both JSC and Hughes (using Leasat F-5) should preclude complacency between now and the mission, and allows for the necessary "back-out" modes, if such are required.

Visual cues during the salvage operations will provide positive indications of the spacecraft condition, i.e., omni antenna deploy, vehicle spin-up, in addition to any X-band transmissions. Any of these would result in mission abort.

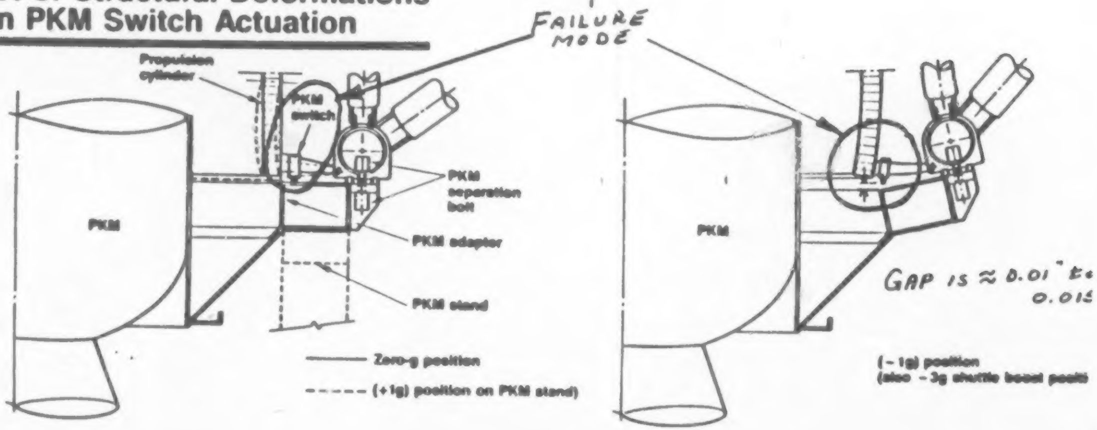
The Hughes built equipment, once installed, will safe the vehicle by (1) locking the separation switch lever in the closed position thereby opening the cradle separation switches, (2) installing shorting plugs to inhibit any internal spacecraft event initiation and allowing only ground commanded initiation, (3) insertion of safe and arm safing pins.

Sneak circuit analyses are being conducted on critical circuits and show no concerns to date. We have been assured that through configuration control that the "as-built" configuration is known. The external configuration is known (unlike the previous on-orbit retrieve/repair missions). Problems associated with on-board propellants (particularly the hypergolics) have been investigated and tests performed. These indicate no safety concerns based on statements made by both JSC and Hughes.

Syncom PES Power/ *CURRENT* Configuration


TP
1KΩ
TP
1KΩ
Battery 1
Battery 2
Pyro bus
Cradle separation switches
PKM separation switches
PES 1
PES 2
PES inhibits
Cradle umbilicals
1KΩ
TP
1KΩ
TP

Effect of Structural Deformations Upon PKM Switch Actuation


FAILURE MODE
Propulsion cylinder
PKM switch
PKM
PKM separation bolt
PKM adapter
PKM stand
PKM

— Zero-g position

---- (+1g) position on PKM stand)

GAP IS ≈ 0.01" to 0.015

(−1g) position
(also −3g shuttle boost positi

D. FACT-FINDING RESULTS OF CALENDAR YEAR 1985

1. Space Transportation System (STS)

a. Orbiter

There have been surprisingly few crisis-type hardware issues. In fact, the major hardware problem is lack of spares that leads to cannibalization. We have dealt with this separately under logistics.

There is one item, though, that warrants review and that is the fuel cell. The bank of cells is fully redundant in a come-home emergency sense, but the mission power loads are high enough that there is not complete redundancy in a mission-power sense. The basic electric power source should be unquestionable. The fuel cell problems have not been fundamental but seem to have been valves, heaters, and the like. This subject is worthy of review to assure the design of these accessories is, in fact, conservative.

Five areas associated with the Orbiter have received most of the Panel's attention: Structural adequacy, avionics hardware and software, brake/steering behavior, landing handling qualities, and the use of automatic systems (such as autobraking and autolanding).

(1) Orbiter Structural Adequacy and Certification Program

The structural life certification program for the Orbiter has been proven by approximately 33 fatigue, fracture, and acoustic supplemental tests, as well as analysis of outboard elevon/flapper-door/wing portion of the rear spar. The last remaining wing root fatigue and fracture analysis has been started, but will not be completed due to lack of funding at this time. It is recognized that the Orbiter is designed for only 100 missions with a scatter factor of four and approximately a 30,000 PSI tension stress level in the lower wing skin. By examining current available fatigue spectra data one can conclude that the fatigue damage is negligible, fracture damage and acoustic loads small. However, in order to have a complete structural life certification program, a short cut analysis should be made and documented.

The calculated ASKA 6.0 (latest loads/stress program) stresses are lower than the stresses from flight test results at wing strain gage locations AB and A14 for 85% launch probability. At this time, it is not practical to revise aero loads, so an additional loading is applied to the wing, known as a "collector force." This added force simulates stresses at wing locations AB and A14 which appear to be slightly conservative on some of the other wing/carry thru structure. The final ASKA 6.0 loads will contain this collector load. The remaining external loads/internal loads work consists of:

(a) additional landing cases - matrix of sink speed vs gross weight.

(b) replace high Q boost loads with a set of Q loads which include "collector load" increments for wing and carry-thru structure.

(c) internal loads-fuselage side without hatch.

Entry internal loads are expected to be completed by February 1986. However, the remainder of the stress analysis and thermal protection subsystem structural analysis is to be completed on schedule, September 1987. All original sets of loads, including high dynamic pressure

(Q) during ascent, will be used to analyze the fuselage and tail surfaces. The structural thermal gradients used have a high degree of confidence based on flight test results and a significant beef up in the mid-fuselage structure resulted from flight test data.

The final check of the wing loads/stresses will be verified by pressure gages and strain gages applied to the OV-102 vehicle. However, it should be noted that a loads calibration program will not be conducted on the Orbiter wing, but may be required if the flight results are questionable.

Since the ASKA 6.0 loads/stress program is to be finished within an allocated budget and time duration, only the primary load path structure (wing, fuselage, tail, and thermal protection subsystem analysis) will be completely documented. Other structural components, e.g., the crew module, will not be well documented.

With regard to redlines and specific Orbiter modifications, it is noted that to meet an 85% launch probability the following modifications are required, based on extrapolation from flight data:

Mod. I. 8 bolts replaced, wing station X = 1307 upper, for all vehicles.
3 bolts replaced, wing station X = 1191 lower, for all vehicles.
Wing station Y = 123, rib cap doublers, for OV-103,104.

Mod. II Wing station X = 1191, external doubler lower for all vehicles.

Mod III (using collector load concept)

o Wing station X = 1249, spar web vert. stiffener	OV-103,104
o Wing station X = 1307, spar web vert. stiffener	OV-103,104
o Add doublers inboard access hole	all vehicles
o Wing station X = 1191, upper cover finger doubler	all vehicles
o Upper surface external doubler	
Proximity of wing station X = 1307	OV-103,104
Aft wing station X = 1307	all vehicles
Inside mid-fuselage carry-thru	OV-103,104
o Wing station X = 1249 access hole doubler	OV-103,104

(Note: These modifications should be the end of any required wing mods. However, there are still two critical items to be evaluated, i.e., the results from the instrumented OV-102 flight test and final 6.0 loads/stress analysis.)

(2) New Avionics Hardware/Software

The Panel has been monitoring three major upgrades for the avionics system of the Shuttle Orbiter--the MMU (Mass Memory Unit), the CPU (Central Processor Unit), and the IMU (Inertial Measurement Unit).

(a) Mass Memory Units

NASA is upgrading the MMUs by adding one card to the tape unit to implement error-correcting codes and to modify the write head--the latter because they have experienced a read-write head wear problem. Several have failed on the ground but fortunately none have failed in flight.

The MMU tape drive is used to change mission phases by loading new programs into the flight computers. The most critical program--namely, the shuttle entry program--is loaded from the MMU into one on-board computer. This load can be, theoretically, accomplished from the ground but the process is slow and has never actually been tried. For a mission abort, the MMU must be used to load the entry program and is, therefore, a critical flight-safety item. Granted, it would require multiple failures (first, an abort, and second, an MMU failure) but the consequences are unacceptable.

The Panel supports the upgrade. However, the cost and schedule (18 months to two years) require NASA's continuing attention.

(b) Central Processor/Input Output Units

Today, each flight computer, consisting of a CPU plus an IOP, uses magnetic core technology and has approximately 104,000 words of 32 bits each. Its speed is 400,000 operations per second. Each box (the CPU and the IOP) weighs 60 pounds and the combination consumes 600 watts of power.

The Panel supports the decision to replace the shuttle computers with those which IBM will be supplying the Air Force for the B-1 bomber (1000 machines) and the F-15 fighter (700 machines). Although IBM would, of course, continue to provide logistic support for the old shuttle computers by keeping a special line open, NASA would be the only customer and the cost to NASA could be unreasonable.

The new computers are smaller, faster, lighter, use less power, and have greater capacity. Each of the new computers weighs 60 pounds (half of the original), provides 256,000 words of memory, executes 1,200,000 operations per second, and consumes 525 watts. With the Air Force as the significant customer, NASA will have logistic support at a fraction of what it would cost if they were to continue with the current shuttle computers.

The NASA versions of the new flight computers are more expensive than those for the Air Force since NASA requires that all parts are to be manufactured in the USA where NASA, through IBM, will be able to directly witness, monitor, and control the processes. This is essential for a flight critical item and it seems odd to the Panel that the Air Force does not demand the same.

Although IBM assures NASA that no changes will be required in the applications software, the Panel recommends that NASA monitor this carefully. Applications software can be expensive to change and retest.

The new computers are scheduled for the middle of 1987 and NASA already has one computer operating in Houston at the IBM laboratory with the new FCOS (flight computer operating system) in place. The old machine has been operating with the necessary software changes to the operating system since January 1985. Now it is in the new computer. NASA has reactivated the GN&C test station to demonstrate the transparency of the new machine to the applications software.

The new computer has new codes and the temptation will be great to use them to "improve" the applications software. To discourage this human foible, the software compiler will not recognize the new codes. The Panel is concerned that this discipline cannot be indefinitely maintained. It was tried without success in the Apollo program.

NASA plans to buy 24 flight and 6 non-flight computers. For logistics, NASA plans to order one new computer each year after the initial purchase. The Panel questions the adequacy of this decision since the lack of spares has always been a significant problem.

(c) Inertial Measurement Units

The upgrading of the IMUs follows a similar pattern. Singer will provide new IMUs with superior performance and at lower cost. The main customer for the new instruments--Bear Claw and the B-1--will provide NASA the opportunity to eliminate the costly dedicated manufacturing line maintained for its use only. Furthermore, these instruments are also expected to be transparent to the shuttle system. In fact, they can even operate as a mixed set--both old and new machines. NASA does not need the improved performance, but will have it as a by-product without changing their specifications.

The new IMU has its own microprocessor which can be an advantage during the prelaunch operation. With the proper software in the IMU processor, any last minute hold-time due to a drifting IMU could be eliminated. Today, as much as 1 1/2 hours of hold-time can occur for such a problem.

The new instruments are lighter--120 pounds versus 175 pounds--and they use less power. The Panel supports the acquisition of this new technology.

(3) Brakes/Nose Wheel Steering

In the Orbiter (shuttle) landing rollout improvement program, the nose wheel steering system has been modified to provide linear response for the first 5 degrees of the 9 degrees total authority with lateral acceleration feedback for smoothing through the general purpose computer (GPC) and is active upon landing. Failure of the GPC results in reversion to the parabolic response direct mode. Results have been satisfactory. However, 9 degrees maximum may not be enough. In the usual case, cross winds are never steady in speed or direction. Thus, the cross wind component will never be known ahead of time for the moment of touchdown or during rollout. Landing wind conditions in case of abort after launch would be the hardest to allow for in planning because of the low probability of such an event and an indeterminate landing site. It is unlikely that winds would be within stated limits at all possible landing sites at any one time. Also, landing procedure calls for off loading the main landing gear by putting the elevons down after nose wheel contact. This, of course, reduces the braking and steering capability with brakes on rollout, and puts greater dependence on nose wheel steering. With these considerations, it would seem that the maximum nose wheel steering angle ought to be increased to 15-20 degrees to deal with high crosswinds, blown tires, inadvertent departure from the hard-surface runway, or a case where drift or skid exceeds the angular limits of the nose wheel, thus leading to possible "groundloop" about the nose wheel. One question remains at this time: Will the nose wheel steering system allow for free-castoring if it goes to a hardover position, that is, a fail-safe, fail-operational condition?

A carbon brake review was conducted by NASA in early December 1985 and resulted in agreement to procure a carbon brake system for the Orbiter and to obtain the system from the current Orbiter brake supplier. There is concern by the STS management about the availability of resources to support the development of the carbon brakes, given the many competing requirements and the projected constrained budget during the 1986 period. The program management considers the development of the carbon brake system to be of the highest priority...and the Panel supports this position as it has in the past.

(4) Landing Handling Qualities

Looking to the future, the concerns with landing handling qualities of the Orbiter which result from the tailless design featuring a low aspect ratio wing and large elevons for longitudinal and lateral control may be corrected through the use of control augmentation devices or surface. This would result in lower landing speeds and improvements in handling qualities. If possible, it would behoove NASA to undertake such a research program with the view of furnishing timely information for future designs of the shuttle type, including possible flight tests of a research-type vehicle at either Ames or Langley Research Centers.

(5) Automation

Automated landings, while still in the program, have not been demonstrated and are not in favor with the current pilot astronauts. They question the system's reliability and prefer a "hands-on" landing capability. However, it would appear that since landings at KSC are deemed mandatory to reduce the turnaround times between missions, the use of the automated system might well be needed to assure meeting the flights-per-year goal. An incongruity appears to exist here in that the launch and ascent portion of the mission is already fully automated and been found to be extremely reliable throughout. The question that arises is: If the flight system for ascent is relied upon, then why not the flight system for landing?

b. Space Shuttle Main Engine

By 1983 there was sufficient data to show that the main engines were being operated near their tolerable margin limits at 104%, and that significant improvements were necessary to permit more than very limited use at the desired 109% of rated power. As reported last year, a three-phase program was defined to address the extensive modifications necessary to improve both operating stress margins and life limiting wear characteristics. Funding constraints in 1984, and continuing in 1985 and for the foreseeable future, have revised the planned program. The restructured program retained the Phase I and Phase II portions to define existing component life and to improve wearout life of the turbo-machinery at both 104% and 109% by decreasing the High Pressure Fuel Turbopump turbine discharge temperature 100°, and by increasing the synchronous whirl margin on the Oxidizer Turbopump by at least 5000 RPM.

The Phase III part of the original program was eliminated and replaced by several other program elements. One of these, labeled Phase II-Plus, will develop and certify a new hot-gas manifold structure. This new manifold will be designed to lower the manifold pressure drop, decrease local peak temperature zones, and improve overall hot-gas flow uniformity.

Additionally, potential engine improvements for the future are being studied in a series of tasks labeled the Test Bed Precursor Program. This activity will develop a single coil heat exchanger, an improved inlet configuration for the High-Power Oxidizer Turbopump, removal of all baffles from the main injector, and a large diameter throat configuration for the main combustion chamber. This will also evaluate further component life extensions by minimizing the start-up and shut-down transient high temperatures.

Beyond these defined but limited tasks to improve known low-margin areas of the existing engine design, there is a new product improvement activity getting underway. This activity will seek new concepts for various critical components or subsystems such as the turbopumps. The objective would be to make major improvements in operating stress margin and/or component wearout life. This long-range improvement activity may involve other rocket engine companies in addition to Rocketdyne. The Panel strongly supports this type of activity because of its leverage on improved reliability at high power levels (109%) and its potential for improved mission performance (>109%).

As of late November 1985, the Phase II program had resulted in many improvements which are now incorporated into the two Certification Engines. Of these, several of the most important are:

- High Pressure Fuel Pump turbine discharge temperature was reduced about 100°R.
- Operating life (no cracks) on both the first and second stage turbine blades of the fuel turbopumps was improved by thermal barrier coatings.

- A margin of almost 7000 RPM was achieved on the High Pressure Oxidizer Turbopump.

- "Life" improvements were made in various other components such as liftoff seals, bearings, sheet metal cases, etc.

On the other hand, several of the planned modifications did not work out, particularly on the oxidizer turbopump. As a result, component life limitations still exist in these areas and will continue to present replacement problems. Therefore, engine use at 109% of rated thrust should still be tightly constrained.

Two Phase II engines will run a kind of "composite certification" program. The results of these tests will be to demonstrate "service life" for various parts of the engine, and indicate a replacement-time schedule for the turbopumps, including even replacement schedules for components of the turbopumps. The basic certification program on each engine will be at a mix of 104% and 109% thrust mission profiles. Of the 10,000 seconds of operation (equal to 20 mission durations), approximately 40% will be run at 109% of rated power. It was hoped to demonstrate 5-flight capability on the turbomachinery (10 mission tests for 5000 seconds). However, parts were changed on the oxidizer pumps, and a weld crack repair done on a fuel pump which then subsequently is to accumulate 5000 seconds. Furthermore, the oxidizer turbopump turbine blades will clearly limit usage to well below 5 missions until the two-piece damper blades can be incorporated in a certification extension program.

The Panel's assessment is that the Phase II engines are fully capable of the 109% for the planetary missions. However, the certification groundrules which permit replacements of various components such as turbopumps or blades, etc., during test series result in a somewhat questionable data base regarding true engine "configuration" operating margins and valid mean-time-between-replacement values. This results from the unknown impact of mixing components with various wearlife histories. The Panel still believes, therefore, that operation at 109% should be limited to only those missions where it is mandatory, and that engines be carefully evaluated after such a flight. The MPT runs to date had gone up to 106%. There were no indications of incipient flow instabilities proximate to changes of state or two-phase flow. The JSC engineering staff, after careful review of the data from the earlier tests, feels confident that a 3 point extrapolation in flow rate can be made with confidence. The Panel supports the three-engine main propulsion system tests at the National Space Technology Laboratories (NSTL), which were scheduled to be completed before any flight is carried out at Full Power Levels.

The Panel review and tour of the SSME facility at Canoga Park were very encouraging. The near-term availability of this facility, with its dedicated special equipment, disciplined procedures, and management focus, should improve significantly the timely availability and reliability of future engines and replacement subsystems. However, unless the new hardware is made available to support a more conservative mean-time-before-replacement schedule on the critical components currently showing wide scatter in lifetime, the "cannibalization" and "parts mixing" which now go on will seriously limit the value and effectiveness of this facility.

c. Solid Rocket Boosters

The steel case Solid Rocket Boosters have been performing as expected for each of the Space Transportation System flights conducted this year (1985). There have been component/system anomalies such as the Hydraulic Power Unit (HPU) turbine overspeed on STS 61-C which caused a pad shutdown. Nonetheless the ground launch system reacted properly and the required change-out of hardware was made. Performance (burning time, thrust vs. time, motor pressures) has been close to predicted each flight. SRB recovery systems, with some exceptions, continue to allow for recovery with little damage.

In response to the Panel's recommendation, the solid rocket Motors are being 100% x-ray inspected, on a periodic basis, to assure that the proper propellant process and quality controls are maintained during the case loading.

The filament wound case (FWC) project Design Certification Review (DCR) was conducted November 18, 1985. The first flight will be STS 62-A using the Vandenberg Air Force Base launch pad system, now scheduled for mid-July 1986. There are a number of "gates" to be completed prior to the Flight Readiness Firing (FRF) which takes place at the VLS in June 1986 in readiness for the first launch. Some of the more significant are:

(1) The FWC STA-2 (structural test article) was tested for prelaunch loads and failed at 118.4% of limit load. The failure mode was not properly identified and is receiving further study. However, the load was not applied to take into consideration joint eccentricity nor was the test article representative of the VLS-1 filament wound flight article. There are process design differences between STA-2

and VLS-1, i.e., use of Plastilock, no time limit for tying down helical ends, and use of substrate glass hoops in lieu of graphite cloth.

STA-2B will be conducted with a new skirt, new forward and aft case, and FWC like the VLS-1 flight article. It will be tested to 140% of limit load during April 1986. In addition, the forward dome joint ultimate pressure and line load applied at the joint will be tested during that same time. It is expected that FWC cavity collapse crushing loads will be tested during July 1986. Increased SRB skirt pre launch loads have been properly identified including load alleviation options.

(2) Filament wound case DM-7 firing showed that at about 80 seconds there was significant thrust oscillation. This requires further analysis to determine the cause and whether there would be any impact on actual flight.

(3) A search is underway for an insulation replacement since the use of asbestos is no longer legal. This is a real concern which may alter the known SRM characteristics.

The lift-off loads affecting the Solid Rocket Booster when launched from the Vandenberg site are estimated to be significantly above the "safe limit" at this time. The prediction methods for prelaunch loads and excursions have been validated by reconstruction analysis. The causes of increased Solid Rocket Booster prelaunch loads have been identified as: transient peak bending moment due to SSME ignition, FWC flexibility amplifying dynamic overshoot, and wind and stacking effects. Several load alleviation options have been identified to provide the needed load reduction. Of these, the one selected is to shim the outboard pad support posts that support the total stack through their attachment to the SRB aft skirt. Additional options, such as placarding west wind velocity, are available. It if it decided to change the SSME start sequence to alleviate the SRB laods there might be a requirement for redefinition of payload bay/cargo interface loads as well.

d. External Tank

The External Tank appears to have little, if any, problems in its role as fuel tank for the Space Shuttle Main Engines. The suspected problem with SOFI tank insulation coming off and impacting the Orbiter at liftoff and during ascent has been eliminated through the use of thousands of holes to preclude adverse pressure difference across the insulation.

There are studies looking at reducing the External Tank weight through judicious removal of metal throughout. This work, based on flight data to date, appears reasonable. However, any reduction in design margins must be carefully studied and understood. The possibility of shell buckling must be kept in mind as was done several years ago during a major weight reduction program.

e. Launch Sites/Vehicle Processing/Logistics

(1) VAFB Launch Complex Development (VLS)

The Panel has been observing the VLS development during the year and was present at the Design Certification Review (DCR) Level I Board meeting, and at the earlier Level II and associated Subsystem Safety Reviews. Excellent working relationships between USAF and NASA personnel are apparent and the progressive resolution of developmental problems in the engineering and construction tasks constitute an impressive overall performance.

The Panel notes the delay in the official launch date for STS-62A from March 1 to mid-July 1986 and views this as being very advantageous from the aspects of safety and readiness. The Flight Readiness Firing (FRF) program will serve to resolve many remaining problems and add confidence in launch safety. Two major tasks still require resolution, namely, the system for ensuring safe burn-off of residual hydrogen in the SSME exhaust duct and the verification of actual launch mount loads on the pad, which are being pursued vigorously. Shims have been added at the launch pad SRB hold-down posts to adjust vehicle loads. The hold-down bolt calibration and joint free play tests will be conducted during a pull test of the two SRBs. It is felt that the loads on the compression side will be large enough to give good results; however, the tension side which has combined compression and tension loads may not be large enough for good calibration data. Since combined loads and not uni-axial loads will be applied, it will be difficult to separate out the various load component effects. These tests are scheduled for the end of the first quarter of 1986.

Final integrated loads analyses, Cycle III prelaunch and lift off loads are close to those previously calculated, adding confidence to the predictions.

Problems associated with the very compact nature of the VLS when compared with KSC have been explored, for example, the provision of an ice suppression system to preclude external tank ice-up prior to launch; elimination of possible re-ingestion of exhaust gases into air conditioning and other systems; and analysis of exhaust and flare-off flame temperatures upon the cryogenics storage tanks.

Quality control procedures in construction and systems seem to have adequate attention and there exists great sensitivity towards this subject following some of the criticisms which were aired publicly in the summer of 1984. The comprehensive review and sign-off procedures between NASA and USAF for design certification and operational readiness leave the Panel with the comfortable feeling that considerations towards thoroughness and safety are paramount.

The Program organizational, staffing and personnel, planning, and training elements appear to be sound and providing the needed strengths to achieve program goals. The test program, including the FRF, appears thorough and one which will pay dividends in successful future launches. And, finally, the cooperative teamwork between the USAF and NASA at the VLS is highly evident and, the Panel believes, a great strength in the national space effort. There are two additional observations which the Panel would note: (1) the 7-day work week, success-oriented schedule, which carries certain risks; (2) over the long term of future launches at VLS, orderly success will depend, in large part, upon retention of a stable, experienced launch team. The Panel urges USAF consideration of a personnel assignment policy which will ensure that future capability.

KSC involvement in VLS operations is detailed in the SPC "STS 1V. Launch Team Support Plan." It outlines KSC support of VLS and is a commitment of the required resources. The plan calls for regular coordination between KSC and VLS counterparts to the extent that each understands the other's status, problems, and concerns. The SPC is in the process of identifying the required KSC personnel by name. At this stage one can only assume the plan will work as described.

The Panel's continued assessment of the launch processing activities at Kennedy Space Center and preparation for the initial launch in 1986 at Vandenberg Air Force Base includes the long-standing concern with the logistics of the Space Transportation System.

(2) KSC Operations

Last year in its annual report the Panel noted that the Shuttle Processing Contractor (SPC) was struggling to handle the burden of work associated with each mission. Factors associated with these difficulties included: unplanned vehicle modifications, unexpected anomalies, shortage of spare parts, shortage of qualified technicians, heavy paperwork burden, planning and communication concerns, and some lack of hardware reliability. The past year has seen progress in resolving these problems but most of them are still present in some degree and will likely persist for the foreseable future, thereby limiting the extent of "operational" status the STS is likely to achieve. Specifically:

(a) SPC Performance. The SPC is improving its internal planning and operations through better communication within the SPC operation and with KSC and other NASA centers. Presence of SPC representatives at the centers has helped considerably. Workflow at the VAB and the pad seems under control. However, the Orbiter Processing Facility (OPF) capacity will have to be increased if the projected flight rate for 1987-1988 is to be achieved. Data systems to provide a common base of information around which to schedule the flow are still being developed, for example, all configuration management systems are outside the SPC's control and will remain so for the foreseeable future. Unplanned modifications now require only about 5% to 8% of the processing time, a considerable improvement; however, about 35% of the time is still devoted to responding to unplanned tests or change-outs resulting from flight concerns and anomalies.

(b) Hardware. The major processing problem is still the unpredictability and unreliability of principal flight and ground items, which is not a problem the SPC can address on its own.

(c) Spares. The advent of Atlantis (OV-104) in service means that, in the short term, the spare parts problem will be more difficult since it will be harder to cannibilize needed parts. NASA's spares acquisition is receiving a great deal of attention but the shortages will exist for months and probably years.

(d) KSC and SPC Reorganizations. Both the SPC (in May) and KSC (in October) announced reorganizations and changes in personnel towards the shared objective of evolving a more "operational" organization.

In addition, agreement was reached on shifting responsibility for orbiter sustaining engineering and logistics from JSC to KSC. However, as expected, the shift to a truly "operational" STS will still be gradual and evolutionary.

(e) Flight rate. Given existing constraints--hardware, spares, modifications, absence of data systems, manifesting difficulties--the goal of 18 flights per year is not within reach at present. A more realistic goal is between 12 and 15 per year. The best composite time to date (best time at each facility, OPF, VAB, Pad) is 44 days. KSC hopes to reduce it to 35 days in the near term and, hopefully to 28 days eventually (goal). One fact is increasingly evident: sophisticated payloads result in long occupancy times in the OPF. Centaur, in particular, is very time consuming in this regard. Such facilities as the Orbiter Maintenance and Repair Facility (OMRF) will help ease the load in the OPF.

(3) Logistics Management

The logistics management responsibility transfer to KSC should be complete by 1988 with JSC retaining control of flight software and avionics, aero loads and thermal analysis and major system upgrades. A KSC/RI Downey contract will be executed on or about January 1986 putting the new arrangements for logistics and sustaining engineering into effect. Included in this program is a plan for RI to develop full TPS shops at KSC by March 1987 using Lockheed and RI tile-making techniques.

The entire spares program is being "restructured" to comply with budget restraints. The premise here appears to be that, since the spares provisioning was actually structured for 24 flights/year, it can be tailored downward for 15-18 flights/year with minimal effect until 1991. A significant element of this restructuring is the use of planned cannibalization and the identification of high-value critical spares items.

A continuing and full-blown effort is needed to upgrade Line Replaceable Units (LRU's). Many LRU's today continue to create serious logistic problems because of extremely limited lives and/or a degree of unreliability. These situations may, in the long run, limit turnaround times and thus the number of flights per year. In the case of extremely high risk designs, NASA should plan ahead by early budgeting of funds for product improvement programs instead of waiting until serious problems exist.

- The Panel understands that limited budgetary allocations are forcing another assessment of spares procurements. Today, cannibalization is a prime means by which many spares are provided. Today, STS 103 is the major "spare parts bin." Because of deferral of initial flight out of Vandenberg, this vehicle is being cannibalized of LRU's to use on other vehicles. What crisis will develop in six months when these units are needed for first flight out of Vandenberg?

Finally, there has to be a minimum allocation of spare units to permit the planned number of flights. Reducing the allocation of spares to fit the budget is going at the problem backwards. If, however, this sort of action becomes a fact of life, then realistic planning should be accomplished to establish the number of missions that can realistically be flown based on such curtailments. The number of missions should be based on real capability.

An SPC safety awards program has been instituted and various mishap, incident and safety alert programs have been established. Safety alert programs exist in each directorate and a suggestion program has been implemented. Some 4,000 SPC employees have now received safety indoctrination and training. A corporate level Safety Advisory Board has been working with KSC and VAFB organizations to further assure STS safety.

2. Shuttle/Centaur

It is quite apparent that the problem of mating the successful Centaur (an unmanned design) with the manned Shuttle was underestimated by everyone. The extent of the changes to Centaur to be compatible with the redundancy and safety requirements of the manned Shuttle are such that new qualification and certification testing is required in many component and subsystem cases. This testing is occurring late in the program and may well be the most critical problem in meeting the schedule. The lateness, it turns out, is not so much a result of technical problems but rather of the initial decision to treat the Centaur as a payload, independent of the Shuttle. Much of the electronic hardware is late owing to problems with parts like the relays and in acquisition of hi-rel solid state devices (an endemic problem for small lot purchasers). This organizational posture inhibited or delayed the recognition of the magnitude of the system integration task posed by Shuttle-Centaur.

The Panel has followed the technical progress of this program and while there are some current worries, they revolve more around the results of unfinished testing for certification rather than perceived real problems. Our concern really is: can the volume of outstanding work be done in time to meet the schedule? The program is aware of this and appropriate emphasis and the show stopper, if there is one, is the sheer magnitude of the work to be done and the lateness of component and system qualification and verification. This problem has been evidenced in previous reviews but should have subsided by now. It has not. Design changes are still being made, for instance some 20 changes in the ground launch system to shift its philosophy from fail safe to fail operational. This is a worthwhile goal and natural launch system evolution but should not burden the system--if it does--prior to Galileo and Ulysses deadlines.

The system should realize that the old philosophy that technical perfection is more important than schedule has changed with Galileo and Ulysses. Management must now schedule with sufficient margin so that adequate technical peformance can be obtained for fixed schedules. It is the difference between a development program and a transportation system. The case in point is that more than a few systems are to be verified or qualified as a result of the wet countdown on the pad. This simply does not allow any time for corrective measures should problems develop. Program management should prioritize the remaining work so that if necessary items essentially in the "confirm for the record" class can be waived.

There are several technical problems that do not appear to be crises but nevertheless are of concern.

First, some Kevlar fibre used in manufacture of helium bottles on the CISS became streaked with oil as a result of a leaking motor. There is some question as to whether or not there is a degredation of fibre strength as a result. Helium is necessary to drain the Centaur tanks in an abort and in that case a helium tank becomes a single failure point. There are not enough new tanks to change out all the suspect tanks and hence the prudent thing would be to reduce tank pressure somewhat until the matter is resolved. A study is underway to see if margin is available to do this.

Second, the five inch fill and drain valve, also a single failure point, albeit with a long and successful history, has experienced some cracking of the metal lug or tang that drives the valve. The analysis testing and explanations seem to be reasonable and the recommended solution is straightforward and seems to entail no risk. The Panel agrees with the actions taken on the basis of the material presented but it is very late in the program for this type of action.

Third, the central control system uses five control units in a voting system. These units use relay logic involving magnetically latched, multi-pole relays. The complexity is such that there are many--in the tens--relays and the circuit is particularly sensitive to a fault where a relay hangs up in midposition. This can occur if contamination can get in between the poles of the magnetic latching mechanism. A second manufacturer has been located whose commercial relays are of significantly better quality. The relays are physically interchangeable and a sufficient supply is on order to change out all such control unit relays over the next couple of months, but again it is late and test time on the new relay banks will be very limited.

3. Space Station

The Panel recognizes that the Space Station program is in the formative period of development of both its organization and staffing and its architecture and baseline operational concepts. The current Phase B activities covering a 21 month period initiates the contracted activities that will lead to the launch and operation of the Space Station program elements which include the station itself, space platforms, and orbital maneuvering vehicles. Concurrent with the competition for the Space Station definition and preliminary design which leads to a thorough understanding of Station systems prior to hardware development, NASA has begun a technology development program that is to enable the incorporation of the "proper" level of advanced, sophisticated systems aboard the Station.

The Phase B period has two sequential parts, System Definition and Preliminary Design. Space Station management has noted that the following is needed prior to the initiation of Prelminary Design:

a. System Definition which covers the manned core, platforms and man-tended interfaces, allocation of functions/resources to each element, and the international aspects.

b. System Requirements which must be met by the design.

c. Plans, schedules and options/alternatives regarding resource allocations, automation and robotics, logistics, etc.

As a result of the Panel's early reviews of the Station, the following comments are made:

a. The Space Station organizational structure is quite complex with roles and missions and responsibilities difficult to discern at times. There is and will be occasional frustration in coping with the myriad of management prejudices and opinions that exist. The program is coping with and satisfying these multiple requirements. The system seems to be working. A process is evolving for crystallizing decisions that attempt to satisfy user requirements as well as budget concerns.

b. There is some question as to whether NASA is adequately qualified to handle the complete integration of Phases C and D--the hardware and software development. NASA is very good at overseeing conceptual efforts. It has in-house depth of knowledge not to be taken in or misled by others, but integrating a large development effort such as STS and now Space Station is something else. To our knowledge NASA has never performed this role before.

c. Since the Space Station exists in an essentially benign environment compared to the Shuttle ascent and entry environment it may be worth the effort to alleviate the ascent environment requirements which drive much of the design for the Space Station equipment and "user" hardware.

d. Since there are many similarities between the STS and Space Station programs, looking into the "lessons learned" relating to the early days of the Shuttle might better define Space Station actions to preclude missteps. This understanding of possible pitfalls for the Space Station program might include insight as to what not to do, thereby preventing inefficient use of resources (money, people, schedule).

Meeting the Space Station Program objectives within a stringent budget requires early, quick, definitive action on the part of progam management at all levels with emphasis on assuring that system engineering and integration organizations have the responsibilities and authority as reflected in the organizational structure. This assumes a commonality of approach to every critical aspect of the Station by the NASA Centers (e.g., safe haven/rescue, design and operational simplicity, crew support for IVA and EVA, safety threats). The following taken from NASA Contractor Report 3854, June 1985, is instructive:

> "It is interesting to trace the evolution of crew safety philosophy through space programs, and to understand the reasons for this evolution. Table 2-2 illustrates key features of these philosophies or goals. The safety philosophy which was baselined for the crew safety alternative strategies study was consistent with these trends, and is shown in Table 2-3, selected from a few potential philosophies."

TABLE 2-2 EXPERIENCE IN THE DEVELOPMENT OF SAFETY PHILOSOPHY IN SPACE PROGRAMS

PROGRAM	SAFETY PHILOSOPHY	RATIONALE
APOLLO	CREW SAFETY GOAL, .999 ABORT CAPABILITY IN ALL MISSION PHASES BACKUP MODES FOR CRITICAL FUNCTIONS	MANY UNKNOWNS AT TIME WORLD-WIDE EXPOSURE OF PROGRAM
APOLLO-SOYUZ	ABORT CAPABILITY IN ALL PHASES BACKUP MODES FOR CRITICAL FUNCTIONS	PROVEN HARDWARE SINGLE MISSION
SKYLAB	LAUNCH CREW AFTER SKYLAB SUCCESSFULLY ORBITED CREW ESCAPE AVAILABLE BY APOLLO CSM	USE OF EXISTING HARDWARE

SPACE SHUTTLE	ABORT CAPABILITY USING THE ORBITER LIMITED CREW ESCAPE SYSTEM DURING ORBITAL FLIGHT TEST	SPACE PROGRAM MATURITY EMPHASIS ON ELIMINATING OR CONTROLLING THREATS RATHER THAN ESCAPING FROM THEM

TABLE 2-3 SPACE STATION PHILOSOPHY PRECEDENCE

CURRENT OPTIONS	COMMENTS
CAUSE NO DAMAGE WHATSOEVER TO SPACE STATION AND NO INJURY TO CREW	DESIRABLE: COST TRADE
CAUSE NO DAMAGE TO SPACE STATION BEYOND ROUTINE MAINTENANCE CAPABILITY	COST TRADE
CAUSE NO DAMAGE TO SPACE STATION OR INJURY TO CREW WHICH WILL RESULT IN A SUSPENSION OF OPERATIONS	BASELINE PHILOSOPHY

4. Life Sciences

This year's activities have shown that Extravehicular Activities (EVA) will continue to be used extensively. The Leasat rescue mission is an outstanding example of EVA. Certainly the space station will require extensive EVA for its construction and operational activities. The current suit continues to function very well despite its limitations. However, there is a perceived need for a more flexible suit in the future that has the capability of operating at a higher pressure than the current suit and its development should beencouraged so that it can succeed the current suit on an attrition basis.

While it is much too early to be resolved, there has been considerable discussion relating to the makeup of the Space Station life sciences module(s). Discussion has covered separate modules for life sciences and materials research versus separation into noisy and quiet modules. The Life Sciences Advisory Committee (LSAC) currently favors the latter approach. However, decisions in this area are yet to be made. Budgetary constraints will also be a factor in the decision process.

The LSAC notes that there is a lack of knowledge relating to the physical condition of astronauts after long duration flights. They have no hesitation about approving in space duty tours of three months or less. Anything beyond this is subject to question. It is true that the Russians have had cosmonauts in space for seven months, but these men required extensive periods of hospitalization after return to earth. NASA's management must continue to support the efforts of the life sciences group to develop the necessary data to establish, with confidence, what the maximum stay in space should be.

NASA is continuing its suit research activities at Ames with the toroidal metal for arms and legs. Perhaps the way to go is not to change suit pressure but to design these arms and legs as replacment for the current ones. The current glove design which is critical is good to 6+ psi.

5. Research Aircraft

Flight research is essential when technology development on potentially important and promising new concepts cannot be completed using analysis, simulation, and ground tests alone. Factors such as geometric scale effects, handling qualities, flight environment, dynamic behavior, pilot/flying qualities interface, and the interactions among multiple discipline technologies and system components, make flight testing an absolute necessity in the investigation of some technology advances. Two current NASA experimental aircraft programs, the forward swept wing X-29A and the X-Wing Rotary-to-fixed blade, involve such flight research.

a. X-29A Research Aircraft

The overriding objective of the X-29 aircraft is to validate and document the benefits of the Forward Swept Wing concept and its interactive technologies by the most affordable means available. The X-29 flight control system is by far the most technical advanced fight control that has ever been flown managing multiple control surfaces and a large negative static stability margin in subsonic flight.

There was a concern about landing with the analog reversion mode of control after failure of the digital system, since project pilot evaluations of the analog mode in the CALSPAN airborne simulation had shown a strong tendency for a potentially dangerous pilot induced oscillation (PIO) in roll in the landing configuration. Subsequent flight tests in the X-29A at safe altitude using precision formation flying tasks in the analog reversion mode and in the landing configuration showed no problem. The CALSPAN simulation is being revised to reflect flight measured derivatives instead of predicted values.

Installation of a new set of sensors for establishing aerodynamic parameters is complete and allows for the variation of gains of the analog reversion mode for safe expansion of the X-29A envelope into the transonic and supersonic flight regimes. The aircraft has flown transonic/sonic to Mach number of about 1.03.

The basic divergence avoidance design of the wing structure has been proven by previous analysis and tests. The maximum allowable "g" is currently 6.4 g. The aircraft has been designed for a maximum of 8 g; however, since the wing was not subjected to an ultimate design load test (to destruct), the 80% design limiation has been applied. The flight program of gradually expanding the allowable from 6.4 g to 8 g should be implemented. This will be necessary if the full value of the integrated, advanced technologies are to be tested. The high degree of test instrumentation and the telemetry should allow this expansion to be done safely.

The aircraft is clean and decelerates slowly. Should incipient flutter be encountered inadvertently, for instance, rapid speed reduction would be essential for survival. More generally, if the dual-pump engine-driven hydraulic system should fail, considered an unlikely event unless the engine should stop rotating (freeze), the emergency hydrazine system will drive the pumps for only seven minutes. At the end of that time the controls will "freeze" and the aircraft will diverge longitudinally in a violent manner when in subsonic flight because of its 35% negative static margin. Unless at low speed (low dynamic pressure) in such a case the aircraft may encounter severe adverse structural or crew impacts. To avert such serious consequences speed brakes would enable rapid slowdown to safe structural speeds for ejection or to enable a safe landing on the desert floor if sufficient time remains. Safety considerations suggest that engineering of speed brakes be initiated for possible later retrofit to both X-29A airframes, with installations to follow at a convenient time in the respective programs. Considering the number of new technlogies involved and the fact that the X-29 is a new aircraft, the flights to date have been remarkably trouble free.

b. X-Wing Rotor Systems Research Aircraft (RSRA)

The X-Wing flight investigation project objectives are to develop and demonstrate, in flight, X-Wing rotor design, controls, and pneumodynamics technologies. This is to be accomplished by concentrating on the conversion from rotor to fixed blade activities, by investigating dynamics, performance, and control within a limited envelope, and thereafter to establish a safe envelope and flight procedures for X-Wing research. The approach being followed is basically to:

(1) Design, build and ground test an X-Wing rotor and control system, including supporting research and technology.

(2) Install the X-Wing and Flight Control System in a modified Rotor Systems Research Aircraft (RSRA) and conduct a 40-hour flight test program.

The X-Wing program has been laboring under an overly optimistic schedule. The Program is working on the leading edge of new and complex technologies, such as:

(1) Circulation-control rotor, encompassing pneumodynamics and its intricate system for metering the required airflows at a high sequential rate, as commanded by digital software.

(2) Starting and stopping a lifting rotor in forward flight, eventually without benefit of a fixed wing (looking beyond the RSRA).

(3) Essentially total dependency on very sophisticated digital electronic systems controlling blade-trailing-edge airflow for lift and control, as well as for higher harmonic vibration suppression, superimposed.

(4) Development of slender, composite rotor blades (swept wings when stopped) which are to resist structural flutter and divergence while carrying, internally, air at temperatures of 250-350 degrees Fahrenheit.

The Program schedules have slipped; the first flight in the stopped-rotor configuration is now being scheduled for the first of 1987. Tests with the propulsion systems test bed (PSTB) and the powered "flying" wind-tunnel model are just getting under way, the latter a key to safe and successful flight of the X-Wing.

The Sikorsky safety program, supported by experienced engineering from the Sikorsky Executive Safety Committee, now seems to have appropriate emphasis and manpower allocated for avoiding or alleviating problems. Slippage of schedules has and will occur because of the sizeable tasks involved and an optimistic and unrealistic original schedule. However, it is mandatory in this program to proceed carefully and thoroughly, regardless of schedules.

The overall safety program for the X-wing/RSRA has many aspects and organizations. These include the Ames and Dryden safety reviews, the Sikorsky Flight Safety Board, and subcontracted analyses by Boeing (BSI in Houston, Texas) for a Hazard Analysis of the entire vehicle and the Northrop Corporation for fixed wing aeroelastic support. The results of the powered model wind tunnel test, the Propulsion System Test Bed (PSTB) dynamic test and the extensive flight control simulation efforts will form the real foundation for verification of the flight safety of the vehicle design.

The principal airframe restrictions of high speed performance for a forward swept winged aircraft is aeroelastic divergence. On the other hand, aeroelastic flutter is usually the limiter for aft swept winged, high performance aircraft. The X-Wing aircraft is unique in that it has both a forward and an aft swept wing when operating in the fixed wing flight mode and therefore could be limited by either flutter or aeroelastic divergence. The traditional procedure for ensuring the absence of these catastropic aeroelastic phenomena is to first design the structure to withstand the flight loads (a strength design) and subsequently to re-analyze the strength design to detemine the point (dynamic pressure and velocity) where flutter or divergence would occur. If this point is outside of the flight envelope, no further design modification is needed. Otherwise, modifications must be made to add additional stiffness to the strength design. Like other theoretical analysis, there are many assumptions and simplifications inherent to the method used for determining the flutter or divergence point; consequently, if the calculated point is near any point of the flight envelope, it is prudent to build an aeroelastic model of the entire aircraft or possibly of the airfoil surface in question (wing or tail). Due primarily to tail rotor restrictions, the maximum dive speed of the RSRA X-Wing has been set at 300 kts. With the standard aeroelastic safety factor this establishes 345 kts at sea level (the region of maximum dynamic pressure) as the aeroelastic design velocity. Albeit, the aircraft design must not possess either a flutter and a divergence point below this velocity. Indeed, the absence of all instabilities at velocities below 345 kts (a dynamic pressure of 300 lb/ft2) must be established by a combination of wind tunnel and analytic programs.

The RSRA/X-Wing represents the first time that an aircraft has been designed to operate at speeds above the airframe aeroelastic instability point. This requires the active control of the aeroelasticly unstable modes by the flight control system (in addition to the unstable rigid body modes); and therefore, makes it the most complex FCS design ever attempted.

6. NASA Aircraft Operations

The Intercenter Aircraft Operations Panel continues its preparation of guideline documents to serve as basis for management instructions to be issued by Headquarters. This is currently the only practical way in which central direction is provided covering all aircraft operations. This process is extremely slow because of the need to obtain approval of all flight operations chiefs, to coordinate these through a central office in Headquarters and to obtain final approval through the NASA heirarchy. Further, the failure, for another year, to appoint a head of the Aircraft Management Office in Headquarters further slows the approval process. There is a great need for a fully qualified operations manager for this program.

Ideally, there would be a single flight operations entity, reporting directly to the Administrator or Deputy Administrator. This entity would have direct and overall responsibility for all flight operations functions, whether administrative or research and development. Flight operations divisions would be located as they are today and would provide service to the various centers, but would not report to the center. Budgets would be centralized and apportioned in accordance with the needs for routine operations and maintenance. All center projects would then become contracts between flight operations and the specific center.

E. NASA'S RESPONSE TO PANEL'S CY 1984 ANNUAL REPORT

Taking each of the items covered in both the Annual Report and the NASA response to it, the following items are "Closed" or "Open" as noted. Of 20 items, 14 are "closed" and 6 are "open." Those that are "open" are still in work with implementation yet to come. The numbering sequence follows that in the NASA response.

1.0 Launch Processing and Logistics

1.1 CLOSED - Panel will continue overview of KSC (NASA and contractor) manpower ability to meet increasing flight rate while maintaining an acceptable level of safety including effects of "operational efficiencies" through 1988-89 to reach 24 flights per year.

1.2 CLOSED - Continue overview of Orbiter Hardware/Software upgrades (other STS elements as applicable) to assure such modifications/changes do not adversely affect reliability, maintainability and/or safety (and sparing requirements).

1.3 CLOSED - Proposed letter from Jesse Moore to Center Directors and NSTS management indicates, "We must take further action to assure the required increase in the Shuttle flight rate which necessitates a steady reduction in turnaround activities. . . . The change and modification work in the OPF (Orbiter) has been highlighted as the key driver . . ." Panel continue oversight of this concern.

1.4 CLOSED - Operations organization and management discussions.

1.5 a. CLOSED - Use of the term "operational" as applied to the Space Transportation System was addressed in great detail. . . . It is not considered an "airline" by NASA.

b. OPEN - Transition of tasks (particularly sustaining engineering) from JSC to KSC. It was noted that a plan was in process and that Panel should follow the implementation of this transition during 1986-87.

c. OPEN - The following additional points:

(1) Space Transportation System Operations Contract (STSOC) at JSC goes into effect January 1, 1986. Panel is requested to follow this as they did the SPC at KSC.

(2) Review the launch constraints being modified in order to increase launch probability and turnaround mods as well.

(3) Comprehensive maintenance plan supposed to have been released September 1985.

(4) Initial lay-in of spares to be completed by October 1987. Status, impact of reduced funding . . . particularly if it affects safety.

2.0 SSME precursor test program to be completed during CY 1985. (OPEN)
Competitive engine (turbopumps) program RFP on the street. (CLOSED) Panel will follow this in 1986.
Phase II and II+ on going. (CLOSED)

3.0 Filament Wound Case follow-up including: Vehicle excursions, lift-off loads alleviation, lift-off drift concerns, flight control stability impacts due to elastic properties, FRF impact on structural adequacy of "single-use" first flight segments (OPEN)

4.1 Results of Rockwell's detailed fracture/fatigue analyses for test article LI-36 (wing/mid-fuselage/aft-fuselage structure being conducted June 85 to January 86. (OPEN)

4.2 Individual Orbiter Delta's and performance capability-structural limitations and load indicator redlines. Follow in 1986 (CLOSED)

4.3 Orbiter Brake Upgrade - Many activities started, some tested, some on-going activities Structural carbon use fail op/fail safe Nose Wheel Steering system vs. current fail safe, etc. Panel follow these in 1986. (CLOSED)

5.0 Development of higher pressure EVA suite. (CLOSED) Note the following from Beggs' response: "The current Agency posture for further space suit developments will be addressed in the Space Station Phase B requirements definition. These requirements will be evaluated, and a determination will be made as to the acceptability of the current Shuttle system, of an enhanced system or the need for a new high pressure system."

6.0 Orbiter OV-102 in an R&D role with appropriate instrumentation. (CLOSED)

7.0 KSC/VAFB common operations. (CLOSED)

8.0 Shuttle/Centaur to adequately conduct tests within current schedule and the availability of resultant analyses is a concern. (OPEN)

9.0 RTG Safety (First Centaur missions). Maintain awareness. (CLOSED)

10.0 NASA's R&D and Administrative aircraft operations management and policy implementation. Panel continues to monitor. (CLOSED)

NASA

National Aeronautics and
Space Administration

Washington, D C
20546

Office of the Administrator

September 25, 1985

Mr. John C. Brizendine
Chairman
Aerospace Safety Advisory Panel
6306 Bixby Hill Road
Long Beach, CA 90815

Dear John:

Enclosed for your consideration is the NASA response to the findings and recommendations provided by the Aerospace Safety Advisory Panel in its Annual Report for 1984.

This year I have also commented on the additional discussions contained in the "Fact Finding" section. Where our positions have been modified from those stated in the past report, I have noted those changes. Comments which specifically address the report's 10 recommendations are submitted in the respective appendices.

The panel's guidance and support is always appreciated. Your inputs have been and continue to be important management tools in the guidance of NASA.

Sincerely,

Original signed by
James M. Beggs

James M. Beggs
Administrator

Enclosure

APPENDICES 1 TO 10, NASA RESPONSE TO THE 1984 ANNUAL ASAP REPORT

APPENDIX 1: LAUNCH PROCESSING AND LOGISTICS

ASAP Recommendation 1.1

NASA management should continue to allocate the human and financial resources required to maintain acceptable levels of safety in what in many respects is still a developmental program from the point of view of the ultimate use of space as well as the maturity of the system.

NASA Response: We believe the level of manpower being applied by the Shuttle Processing Contractor (SPC) at both KSC and VAFB is commensurate with the high safety standards and requirements of a manned space flight program and NASA's overall program goal of evolving the Space Shuttle into a cost effective operation. The maturing, developmental nature of the program is recognized and the essential need for constant safety and quality assurance vigilance is a continuing concern. NASA is committed to continuation of the required resources to maintain an acceptable level of safety.

The number of KSC Shuttle operational personnel remains fairly stable. The number decreased when the SPC came on board early in FY 84 and has remained almost constant for the last year (decreased approximately 1%). We expect it to increase some in the next 1½ years because of additional work stations coming on-line (i.e., Pad B, MLP-3, Logistic Warehouse), and then decrease with operational efficiencies through 1988-89.

The KSC safety policy has not changed since the SPC concept has been implemented. However, the contractor now has responsibility for the implementation of that safety policy with NASA civil servants practicing an oversight and surveillance role. The number of safety personnel actually increased from approximately 35 to 45 under the SPC. This increase was considered necessary as a result of the increased launch processing activity and higher launch rate.

ASAP Recommendation 1.2

Modifications to the Orbiter -- such as main engine, structure, avionics, and brakes -- should be directed at improving reliability, maintainability, and safety as well as achieving additional increments in performance.

NASA Response: I concur wholeheartedly with this recommendation. A large percentage of Orbiter changes are made for these reasons. Examples of modifications which will improve reliability, maintainability and/or safety are the improved APU, IMU, fuel cell, brakes and nose wheel steering. The EEE parts program is also directed at improving reliability for the GPC and IMU. Engine Improvements are discussed in Appendix 2.

ASAP Recommendation 1.3

NASA management should make a concerted effort to identify and prepare for Orbiter modifications prior to commencement of the launch processing sequence. "Freeze point" discipline must be maintained. Unexpected changes and modifications must be held to a minimum if the Shuttle Processing Contractor (SPC) is to achieve the projected flight rate.

NASA Response: Over the past year, the Level 2 and 3 program offices have made concerted efforts to identify and permit preparations at KSC for Orbiter modifications prior to commencement of the launch processing sequence. The Panel is invited to JSC to receive full details on the operation of the system, referred to as the Rockwell BARS (Baseline Accounting and Reporting System). That system provides KSC with computer access to all mods. Mods are identified on a per flight basis as well as a total listing. Changes are prioritized as either mandatory prior to a particular flight or as those which are to be installed at the first available opportunity. A program directive (PRCBD S31730) has been issued which is the implementing document. Copies of the presentation material and the directive are available for review.

ASAP Recommendation 1.4

Vesting overall Shuttle management in an "operations entity" at NASA Headquarters would help achieve acceptable levels of efficiency, productivity, and schedule reliability during this period of "developmental evolution." The Panel has made this recommendation in past years and NASA management is presently examining this and related issues through the Shuttle Operations Strategic Planning Group, the Smylie Committee.

NASA Response: I feel that the Agency is making strides in the direction of an operations entity which the Panel suggests is the proper course to pursue. Since I reported to you last year, the SPC (Shuttle Processing Contractor) is onboard and has successfully launched all vehicles since STS 41C. The contract for operations at JSC is expected to be awarded in January 1986.

With regard to changes at Headquarters, there are several developments that you should be aware of. Within the last year NASA established two groups to study the Space Shuttle's organizational setting and role within NASA. The groups are the Shuttle Operations Strategic Planning Group, chaired by Mr. Ed Smylie and the Shuttle Operations Fencing Team chaired by Mr. Charles Gunn. Copies of the reports from these two groups have been transmitted to the Panel.

The Strategic Planning Group concluded that, for the foreseeable future, the Space Shuttle should continue to be managed and operated by NASA, and outlined several organizational alternatives we are now considering. The Shuttle Operations Fencing Team concluded that the Shuttle operating budgets, organizations, and facilities are now effectively segregated, or "fenced," at each of the operating centers and the consolidation of Shuttle operations contracts (e.g., BOC (Base Operations Contractor), SPC (Shuttle Processing Contractor), STSOC (Space Transportation System Operations Contractor) and FEPC (Flight Equipment Processing Contractor)), plus the evolution from fixed fee to cost incentive contracts, further promotes fencing of the Shuttle from other NASA programs. The Fencing Team, in consonance with the ASAP recommendation, also recognized a need to change the balance between development and operations within NASA Headquarters to place more employees in operations. The Office of Space Flight has reorganized to better focus on requirements, issues, and procedures, which are dominant in operations, as opposed to acquisition and development.

ASAP Recommendation 1.5

NASA management would be well advised to avoid advertising the Shuttle as being "operational" in the airline sense when it clearly isn't. More to the point, however, is the fact that Shuttle operations for the next 5 to 10 years are not likely to achieve the "routine" character associated with commercial airline operations. Given this reality, the continuing use of the term "operational" simply compounds the unique management challenge of guiding the STS through this period of "developmental evolution." NASA should continue to focus on making the STS as efficient, productive and reliable as possible, while the research and development flights are defining the commercial use of space.

NASA Response: National Security Decision Directive (NSDD) 42 states that NASA's first priority is to make the STS fully operational and cost-effective in providing routine access to space. NSDD 144 directed that NASA and DOD jointly define "fully operational and cost-effective" and the specific steps leading to that status. Our definition is provided below, and you will note that nowhere is a reference or an analogy made to airline characteristics. As illustrated elsewhere in this report, I believe we have set in place policies, procedures, practices and processes to make the STS as efficient, productive and reliable as possible, while balancing the necessity to be cost-effective in the world's marketplace.

Excerpt from NSDD 144

DEFINITION OF A FULLY OPERATIONAL AND COST-EFFECTIVE SPACE TRANSPORTATION SYSTEM

Introduction

NASA's highest priority is to make the Nation's Space Transportation System (STS) fully operational and cost-effective in providing routine access to space. Fully operational means that the STS is ready and available for routine use in the intended operational environment to achieve the committed operational objectives. This means that critical performance capabilities have been verified by flight demonstration; that adequate logistic support for the systems is in place; that the ground and flight processing capabilities are adequate to support the committed flight schedule of up to 24 flights per year with margins for routine contingencies attendant with a flight surge capability; and that the appropriate operational management capabilities are in place. Cost-effective means that the Shuttle provides space services for specific levels of mission capabilities with an effectiveness at least equivalent to the cost of alternative systems. The definition must recognize the unique capabilities of the Shuttle that cannot now be attained by alternative systems. Cost-effectiveness is a function of the unique capabilities required by each category of mission (e.g., launch and deploy, retrieval, on-orbit repair, refuel, assembly, life sciences R&D, and man tended services and applications). As the Shuttle becomes fully operational, its cost-effectiveness in all categories across its full spectrum of space missions can be improved by continued reduction in operating costs.

Joint NASA/DOD STS program capabilities, requirements, and plans for development, activation and operation of the Space Shuttle through the mid-1990's are defined in the NASA/DOD Space Transportation System Master Plan, Part I: Baseline Operations Plan, chartered by the NASA/DOD Aeronautics and Astronautics Coordinating Board. This plan was published in mid 1985 and states:

I. Fully Operational STS

The STS is fully operational when specified levels of capability and maturity have been achieved in (A) Systems Capabilities and (B) Management.

The Agency continues its evolutionary process of becoming "operational." Great strides were taken this spring when JSC and KSC reached an agreement on definition of center roles and responsibilities for the STS operations era. As stated in the JSC memorandum, dated May 7, 1985,

> "KSC will assume responsibility for the integrity of and sustaining engineering for all certified Orbiter flight hardware, flight readiness certification and Orbiter configuration control. KSC will also be responsible for flight hardware spares and logistics activity. The sustaining engineering responsibility includes the LSSC, which may be an early transition step.
>
> JSC will retain responsibility for development and certification of new or upgraded Orbiter flight hardware. JSC will also retain responsibility for long lead planning for the fleet/manifest, mission analysis, flight software, avionics as a system and the analytical disciplines such as loads, thermal, aero and the like. JSC will continue to provide on-call engineering support as required."

A plan to implement that policy is being developed by KSC.

Discussion of Fact Finding Points for Recommendation 1

The following paragraphs address points raised by the Panel in the "Fact Finding" section of your report.

With regard to the ASAP comment that "there must be no disruption in the operational support adequacy and ability to safely launch and turnaround the Space Transportation System as currently operating," NASA continues to assess methods of reducing turnaround times and optimizing operations. Where a decision is made to reduce or optimize, careful analysis is given to ensure that operational adequacy is maintained and that the safety of the Shuttle during turnaround and launch and landing operations is always maintained.

We concur with the Panel's statement that "Personnel are a key resource and provisions must be made to "feed in" new people to replace, as necessary, those leaving." This has been one of the major goals which I established for NASA.

During FY 84, of the 384 scientist and engineer (S&E) new hires, in NASA, 246 (64%) were at the GS-9 grade or below. This represents a continuation of the "fresh-out" initiatives begun in FY 82. For FY 82-84, 1449 S&E's were hired and 1049 (72%) were at the GS-9 grade or below.

The Panel notes that "traditional organization arrangements, review methodology, handling of payloads, and system certifications cannot remain static but will change with STS maturity and accompanying knowledge and objectives" and that "complacency at any point in the process must be guarded against." NASA is presently seeking an STS Operations Contract contractor to consolidate the Shuttle operations tasks at JSC. The purpose is to improve cost-effectiveness via consolidations of mission operations during the STS operations era while maintaining a high level of technical performance. The contractor will be given considerable latitude in forming and developing an approach based on his unique capabilities and experiences. The STS basic program objective of reliable and economical space transportation is paramount; conformance with the historical "business as usual" approach, typical of development and test programs, is not. We expect this new contractor to begin operation in January 1986.

From an STS cargo processing standpoint, there are a number of enhancements underway or planned that will reduce the handling times of STS payloads. Our customers are encouraged to qualify payloads for flight ready storage in order to minimize their pre-launch time at the launch site. They are also urged to provide an adequate number of personnel to facilitate multiple-shift work as required, so as to minimize stay time.

On a payload-by-payload basis, technical assessments are conducted to determine whether stand alone, simulated mission sequence, or end-to-end testing can be eliminated. A continuing effort is underway at JSC to identify ways to simplify the payload-to-Orbiter interfaces. As interfaces are simplified, payload installation and subsequent check-out procedures will be streamlined, resulting in time savings. Although efforts are being made to minimize or delete unnecessary payload operations, care will continue to be taken to insure that necessary procedures are not neglected.

The ASAP observes (page 39) that "a specific aspect of the management process which bears further attention are the 'Program Freeze Points' and their use. Program freeze points are established at specific intervals during flight processing. Freeze points are defined as those points in time when the design, definition, and content of the cargo, integration hardware/software and flight design, vehicle flight hardware/software, crew activities/stowage and launch site flow are complete. Subsequent to these points, only mandatory changes to the hardware, software or affected documentation are permitted (mandatory changes are those necessary to ensure crew/vehicle safety and/or accomplishment of primary mission objectives). Such freeze points are established for each mission."

The management of "Freeze Points" is receiving significant attention within NASA and the Shuttle customer community. Changes to the design/definition/content decisions made at the

"Freeze Points" are being resisted so that the mission design and planning can proceed in an orderly fashion. The schedule of the Freeze Points is a compromise between the desires of the customers (who would like the "Freeze Points" scheduled as late as possible to allow flexibility in cargo design) and the mission planners (who would like the "Freeze Points" scheduled as early as possible to allow time for mission design). NASA is developing techniques and tools to increase the productivity in the planning efforts and, thus, better support the customers.

"Preparations for contingency landing site (CLS) activities must be planned to meet mission goals and to minimize expenditure of resources which can best be used elsewhere. (Refer to page 37) CLS activities have been planned with a minimum investment of resources but still provide the ability to support Orbiter operations with safe back-up options. It is agreed these resources could be used elsewhere, but where considered essential, the CLS capability has been provided. Particular CLS attention is being given to the missions involving the launch of radioisotope thermal-electric generators.

"Operational efficiency, as measured by such things as turnaround time reduction, hardware increased reliability (increased mean time between failures), increased crew effectiveness and weather predicting, are all part of operations. Since day of launch winds can affect vehicle aerodynamic loads, better trajectory shaping and load reduction can be accomplished with winds as near to T-0 as possible. The actual "doing" part of launch and landing, along with retrieval of SRB's, has been proven through the STS missions to date. However, one area of continuing interest is the impact of flight vehicle and ground equipment hardware and software changes (both generic and mission unique) and procedural changes upon the ground sites, including modifications to the launch constraints or so-called "red and blue lines."

Operational efficiency has been improving, as indicated by the turnaround time improvement from 187 days for STS-2, to a current average in the neighborhood of 55 days; our best turnaround time to date was 50 days for STS 51-B. Efforts are continuing to achieve additional efficiencies in several functional areas. The weather predicting capability is now being improved through the addition of communications, radar, and other equipment. Also, plans are being formulated for more refined, long-range weather predicting improvement through advanced technology surveys, studies, and applications. Changes are being minimized. Winds are measured by Jimsphere down to L-3.5 hours.

The Panel iterates on page 40 that "a complementary area of interest is the pre- and post-flight mission reviews. The Panel notes, as it has in the past (see Annual Report dated January 1982 and January 1983), that the management review processes remain little changed from those used on early missions. With an increased flight rate, maturing systems and hands-on resources, there remains the involvement of a large number of high level management personnel. Changes made to date in this review system have certainly helped but further streamlining should be expected in the future." It should be noted that the reviews conducted and the reports generated in support of the Shuttle missions are undergoing continual evaluation as to their content and requirement. This effort, even in a "business as usual" context, is decreasing as the program matures and there are fewer problems to be reported and coordinated. Efforts have been reduced through abbreviated pre- and post-mission reports, Headquarters mission monitoring and reporting, and follow-up briefings. I am encouraging the Headquarters staff to reduce the amount of required paperwork, as well as their direct involvement, in these activities. However, it must be anticipated that where unique missions are flown, interest and involvement on the part of high level management will continue.

"The Panel (ASAP) has previously recommended that a comprehensive maintenance plan be established partly as a system to prevent interruptions in the launch rate through the 1990 period and beyond, and partly to provide a more rational basis for the current logistics plan which is now underway. While some elements of maintenance planning are evident, there does not yet appear to be a total plan which would include contingencies such as multiple SSME failures or planned withdrawal of an Orbiter for structural fatigue examination or replacement. This sort of maintenance overview may indeed exist and will be examined by the Panel in the future." (Page 40)

The Panel's observations are proper and a comprehensive maintenance plan is being developed by the Johnson Space Center Logistics Office (LG). The estimated release date is September 1985. We welcome your review and comments.

"The SPC in its operations has uncovered some problems; the most serious of which is shortage of spares. Line replaceable units (units designed for rapid replacement) are in short supply and the only alternative is to cannibalize -- that is to remove a working component from another Orbiter and pay back the loan when the part becomes available. This is a costly procedure in terms of manhours and delay, but the safety implications are those of violating a certified system to get the necessary parts. Another significant problem is that of the workload caused by the incorporation of modifications on the Orbiter at KSC. Even though modifications are scrutinized before the decision is made to incorporate them, further controls may have to be instituted, if the launch rate requirements are to be met. The next year or so should see some improvement in logistics and support problems as the SPC program advances satisfactorily."

Although some spares shortages do exist, the requisition fill rates of both flight hardware (FH) and ground support equipment (GSE) are continually improving. The KSC requisition fill rates for November 1984 through February 1985 are:

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY
FH	88.7	90.9	91.8	90.5
GSE	82.2	84.1	85.0	85.5

Our initial lay-in of spares will be completed in October 1986.

"If OV-105 is ever funded, it will have the beneficial effect of providing a standby vehicle in the Orbiter fleet, but at the same time will sop up most of the available production spares thus exacerbating the problems surrounding each individual launch toward the 1990's. The goal is presently some 20 flights per year from KSC and 4 per year from VAFB. There has been a sizable transfer of experienced personnel from KSC to VAFB and we were told that there are about 1200 LSOC people there now." The long lead time between funding and delivery of OV-105 -- if and when it is funded -- will allow adequate lead time for lay-in of supporting spares. A further logistics benefit to the funding of OV-105 would be that "production line spares" would be available to support the entire Shuttle program for a longer period of time than is presently envisioned. This will undoubtedly further improve our spares long-term support posture.

APPENDIX 2. SPACE SHUTTLE MAIN ENGINES (SSME'S)

ASAP Recommendation

The modified improvement program should be pursued vigorously. All reasonable effort should be exerted to develop the new hot gas manifold and to incorporate it at the earliest date feasible. Activity to reduce start and shutdown temperature transients should be added to the "Phase II+" program. Mission planning should continue to consider 104% RPL thrust as the normal operating level for the engines. We will use the 109% RPL thrust capability only for those missions dependent on the higher thrust and as an abort capability.

NASA Response: The precursor test program scheduled to be completed during CY 85 will include a limited test series (7 to 11 tests) with the large throat main combustion chamber designed to reduce turbine temperatures, modification to control valves to ameliorate start transient turbine temperature spikes and a single tube heat exchanger. The test series will include "bomb" tests of the chamber to determine stability margin and to assess the need for baffles or acoustic cavities. Elimination of these stability aids could provide performance improvement in terms of increased specific impulse.

The competitive engine program is structured to provide an alternative approach to engine design improvements/modifications which improve reliability and safety by increasing operating margin and extending hardware life.

The baseline program consisting of the Phase II and Phase II+ activities is underway with the Phase II certification testing having been initiated in March 1985 and scheduled to be complete in October 1985. The Phase II+ development testing with the new, 2 duct, hot gas manifold is scheduled to start in May 1986. I should note that this program does not include LOX pump redesign which was indicated in last year's response to the Panel.

The baseline program is now just getting into certification testing, and it is premature to speculate how well these improvements will improve reliability maintainability, safety, and performance. Improved life and operating margin is being realized in the development program testing to date. Until these improvements are made, we plan to limit the current engine to 104%.

APPENDIX 3. SPACE SHUTTLE SOLID ROCKET BOOSTER (SRM/SRB)

ASAP Recommendation

An analysis and tests be performed on the filament wound case with the total stack to establish lift-off loads and vehicle excursions considering the lower modal frequencies.

> NASA Response: The analysis conducted predicted a flexible filament wound case. The initial quarter scale testing at MSFC showed that the SRB joint free play was a potential source of increased vehicle on-pad excursions. Tests to the full 125% flight load limit will be performed on a flight segment by January 1986.
>
> As test data from FWC hydroproof testing and sag data recorded during the DM-6 static firing became available, it was found that the entire SRB FWC joint area was much less stiff than expected. The DM-7 Static Test confirmed the DM-6 test results. New SRB FWC dynamic math models were constructed by MSFC, and a special analysis effort of the stacked vehicle was initiated to assess the effect of the recorded stiffness in five areas already thought to be marginal. This assessment was completed in late December 1984 with results as follows in the five problem areas:
>
> 1. Vehicle on Pad Excursions (FWC, VAFB): Predicted excursions exceed both the ICD and the range of previous tests. The impact of these results is being assessed by KSC. A new series of tests, exceeding the predicted values by 10%, is being planned for the Launch Equipment Test Facility and will include a new "haunch" assembly simulating the VAFB umbilicals. Results will be verified by the "twang" test at VAFB and supported by Structural Test Article testing at MSFC
>
> 2. Lift-off Loads: Significant load increases were predicted at the SRB/ET forward attachment and in crew cabin accelerations. The increased attachment loads have been assessed to be within the structural capability of the vehicle, and the effect on payloads of the increased accelerations has been determined to be acceptable.
>
> 3. Lift-off Drift: The clearance between the SRB and the facility during lift-off are essentially unchanged, and the minimum four inch exclusion envelope is not violated.
>
> 4. SRB Hold Down Bolt Load: An increase of approximately three percent in maximum bolt tensile load, which occurs at the maximum excursion during SSME build-up, is predicted. MSFC has assessed this increase to be

acceptable due to other actions taken to alleviate the bolt load problem.

5. Flight Control Stability Margin: The predicted reduction in the SRB bending mode frequency was determined to be unacceptable. The flight control systems software has been redesigned to insure acceptable margins. These changes will be incorporated for VLS-1.

Because of the lack of actual test data on the FWC configuration, the development of the math model representations used in these studies has been very difficult and uncertain. The DM-6 and DM-7 sag tests were the first chances to assess actual bending stiffness, and resulted in the most significant change. Special measurements during the DM-7 test did confirm the bending model parameters. Since the interim assessment discussed above, several minor changes that do not affect the above problems have been incorporated in the math models, and the next major analysis cycle is underway. This is the final planned set of studies of the Shuttle/FWC combination and is considered to be the primary verification analysis.

Due to the lack of maturity of our understanding of the FWC properties, additional testing to demonstrate the validity of the verification analysis is considered necessary. A test is planned at VAFB using a fully stacked SRB. The currently baselined twang test will be expanded to include sine-dwell, and random survey testing. A special pull test, using the two SRM's on VLS-1, was also recently baselined to evaluate joint free play and bolt load effects.

Completion of the planned analysis activities and the testing identified above will insure that adequate margins exist in these identified. A flight readiness firing would demonstrate adequate margins regarding bolt loads and excursions driven by SSME build-up, but these items must be demonstrated prior to attempting either an FRF or launch.

APPENDIX 4. ORBITER STRUCTURAL LIFE CERTIFICATION AND STRUCTURAL ADEQUACY

ASAP Recommendation (1)

The Panel agrees with the decision to certify these two articles (LI (Line Item) 31 and LI 36) by analysis. A detailed analysis plan for the two test articles should be developed and implemented to fulfill the certification program for 100 missions.

> NASA Response: A plan to analyze the two test articles does exist. The Orbiter vehicle end item specification requires certification of the Orbiter primary structure for 100 missions times a scatter factor of four. Detailed fracture/fatigue analysis has been completed for LI 31, the wing/elevon structure, and the analysis confirms the capability of the structure to be certified in accordance with the specification. Detailed fracture/fatigue analysis for "LI 36," the wing/mid-fuselage/aft-fuselage structure, started in June 1985. Completion is estimated by January, 1986.

ASAP Recommendation (2)

Conduct a systematic review and document the structural differences, safety margins and major logistics impacts for each Orbiter vehicle. In recognition of these differences, baseline the performance envelope for each Orbiter and, as required, determine the trade-offs between any structural/aerodynamic modifications and performance.

> NASA Response: Trade-off studies between structural and aerodynamic modifications and performance have been conducted for OV-103 and 104. The most productive option in terms of performance gain versus mod complexity has been implemented. This option, which strengthens the X0=1365 wing spar and upper rib caps, results in a net payload gain of approximately 4,000 pounds.

OV-102 has been modified based on the 5.4 loads to bring it in line with the rest of the fleet. OV-099 was modified for 5.4 loads prior to delivery while OV-103 and OV-104 were built to the 5.4 loads. Wing leading edge moment ties have now been added to all four orbiters. Mid-fuselage strap (torsional restraints) additions have been completed on OV-099 and OV-102 and will be completed by flight 10 of OV-103 and flight 7 of OV-104.

With the completion of the modifications stated above, the primary remaining differences between the Orbiter vehicles from a performance/structural viewpoint will be as follows:

a) OV-102 weight is 5,000 pounds greater than the other vehicles, a major contributor being additional flight instrumentation

b) OV-103 and 104 have WTR capability due to upgraded upper surface TPS

c) OV-099 and 104 have Centaur carrying capability

For the near term, structural limitations and load indicator redlines are being provided on a flight-by-flight basis. Long range plans call for the development of a common set of capabilities for all vehicles while taking into account the remaining differences noted above. This will provide the maximum possible launch flexibility in terms of Orbiter vehicle interchangeability, an increasingly important factor as the flight rate increases.

The Panel has expressed concern in the past over Orbiter brakes and the thermal protection subsystem. I have received several briefings on that hardware, in February and May on the brakes and in March on the waterproofing of the tiles. The JSC Director has written Headquarters on July 24, 1985, that they are pursuing a comprehensive and aggressive program to address the landing/deceleration system problems of the Orbiter which consist of a dynamic stability problem and a heat/energy capacity problem. Some key elements of this program are provided below:

1. Provide the changes necessary for routine landings at KSC. The nose wheel steering is being modified to be fail safe, the modifications being accomplished on STS-61A. That will reduce braking requirements by elimination of the need for differential braking for steering.

2. Testing and analysis are being performed to provide increased system damping and balancing of brake puck pressures.

3. A stiffer main landing gear axle is being incorporated. Designs for an automatic braking system and thicker out-board brake stators are underway.

4. We plan to duplicate the brake problems and assess fixes via an analytical and test activity (at Goodrich) and to improve flight data collection through additional brake instrumentation. Langley is conducting tests to determine the impact of runway surface on brake performance.

5. We have initiated a preliminary design activity for a structural carbon brake system. A PDR is scheduled for September 1985.

6. With the upgrading of the Wright Patterson AFB test facility, the Orbiter strut, wheel, and braking system will be tested with a considerably increased test fidelity.

APPENDIX 5. SPACE EXTRA-VEHICULAR ACTIVITIES (EVA'S) AND LIFE SCIENCES

ASAP Recommendation

NASA should encourage the development of an advanced higher pressure EVA suit to replace the existing unit.

NASA Response: The current Shuttle Space suit has performed excellently since STS-5. All design reach and flexibility requirements have been met and exceed that required for an EVA.

The low pressure suit (4.3 PSIA) maximizes flexibility and glove dexterity but requires prebreathing to eliminate the bends. A higher pressure suit would reduce prebreathe concerns but would sacrifice glove dexterity and increase suit leakage. Of course, the other approach to elimination of prebreathe is reduced cabin pressure. Reduced cabin pressure is the Shuttle's chosen option for bends control.

The current Agency posture for further space suit developments will be addressed in the Space Station B requirements definition. These requirements will be evaluated, and a determination will be made as to the acceptability of the current Shuttle system, of an enhanced system or the need for a new high pressure system. This decision will be made during the FY 1986 or FY 1987 time period.

Key to the decision will be the amount of EVA required and the selected Space Station cabin pressure. The Agency's stated goal is to have one EMU/EVA system, which will satisfy all requirements and be cost effective.

The addition of telemetered data during EVA will reduce requirements for crew call down of data and will expand the metabolic data base for EVA planning. This effort is currently underway and will use the EKG channel on a shared basis with life support system data.

APPENDIX 6. USE OF ORBITER -- 102 IN R&D ROLE

ASAP Recommendation

Orbiter OV-102 is the most suitably instrumented of the Shuttle fleet and should be utilized as a research and development vehicle in addition to its normal mission activities.

NASA Response: NASA agrees with the ASAP recommendation and is actively engaged in a two part data gathering program which will utilize OV-102 as well as the other vehicles in a research and development effort.

One part of the program provides the necessary instrumentation and data to expand the operational Orbiter envelope to its fullest. Data to be gathered as a result of this part of the program includes wing loads, mid-fuselage thermal gradients, compartment vent pressures, WTR launch conditions, brake accelerations and strains, flutter, CG expansion, payload bay environment, and TPS life.

The second part of the program will provide basic data useful to follow-on space vehicles. This part of the program is referred to as the OEX (Orbiter Experiments). The magnitude of the effort can be seen from the enclosed OEX Flight Schedule. The OEX includes the Aerodynamic Coefficient Instrumentation Package (ACIP), the Shuttle Entry Air Data System (SEADS), the Shuttle Infrared Leeside Temperature Sensor (SILTS) and the Shuttle Upper atmosphere Mass Spectrometer (SUMS).

OEX FLIGHT SCHEDULE

FLIGHT NUMBER	41D 14	41G 17	51A 19	51C 20	51B 21	51E 22	51D 23	51B 24	51G 25	51F 26	51I 27	51J 28	61A 30	61B 31	61C 32	51L 33	62A 1	61E 34	61F 35	61G 36	61H 37	61M 38	61J 39	61K 40	61I 41	62B 2	61L 42	71A 43	71B 44	71C 45	71D 46	71E 47
FLIGHT DATE	8/84	10/84	11/84	12/84	2/85	2/85	3/85	4/85	6/85	7/85	8/85	9/85	10/85	11/85	12/85	1/86	3/86	3/86	5/86	5/86	6/86	7/86	8/86	9/86	9/86	9/86	10/86	10/86	11/86	12/86	1/87	2/87
OV-099 CHALL		X		X		X		X		X			X			X			X			X			X				X			X
OV-102 COLUM															⊗			X			⊗			⊗				⊗			⊗	
OV-103 DISCO	X		X		X		X		X		X						X									X						
OV-104 ATLAN												X		X						X			X				X			X		
ACIP/ HIRAP		X		X		X		X		X			X	X	X	X		X	X		X	X		X	X			X	X		X	X
SEADS															X			X			X			X				X			X	
SUMS															X						X			X				X			X	
SSO		X		X		X		X		X			X	X	X	X		X	X		X	X		X	X			X	X		X	X
OASIS					NOT FLOWN	NOT FLOWN																										
CSE																																
TGHE																																
TABI																																
DIR BOND																																
SILTS															X			X			X			X				X			X	X
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5800

⊗ DENOTES FLIGHT WITH FULL COMPLEMENT OF OEX EXPERIMENTS

June 1985

APPENDIX 7. KENNEDY SPACE CENTER (KSC) AND VANDENBERG AIR FORCE BASE (VAFB) COMMON OPERATIONS

ASAP Recommendation

Until such time as the KSC and VAFB sites have their own launch crews and dedicated Orbiters, the manifesting or scheduling activity should have a procedure to consider the schedule effects on crews who must travel back and forth. Also, attention must be given to the availability of specific Orbiters that may be required by specific missions. This is particularly critical in those cases where the DOD may be required to ask for an unscheduled launch.

> NASA Response: The Agency's present approach is to provide maximum utilization of SPC personnel at both launch sites, and mission planning at both facilities to account for the schedule effects on crews who serve those sites. In the case of early flights from VAFB, launch team personnel from both KSC and the SPC will assist. In addition, consideration is being given to the maximum use of SPC personnel at VAFB for various tasks, such as Orbiter mods, during non-launch periods. In our manifest planning, orbiter use is also being optimized between launch sites with consideration being made for unique DOD requirements. Unscheduled launches will require a review as the need arises.

Discussion of Fact Finding Points

The ASAP observes that "for some substantial startup time -- years not months -- the rate of Shuttle launches from VAFB will be too low to justify the establishment of a complete launch crew that would be inactive for most of the year. The present plan is to use selected military personnel who have had training at KSC as permanent VAFB personnel and at each launch move the rest of the required crew from the NASA ranks at KSC. None of these people have had the opportunity to train at VAFB and hence the crews must be in residence some appreciable time before each launch, most particularly before the first launch at VAFB."

"While this would seem to be a straight-forward scheduling job, it is complicated by two facts. First, the DOD may be required by circumstances to ask for an unscheduled launch on short notice. Second, the Orbiters are not identical from a structural load capability and certain loads may require certain Orbiters. The scheduling problem is not bad if one formally identified it and is aware of the limitations it may impose on the joint operations. A subsidiary but important point is that the launch crews have not trained at VAFB nor has the facility been exercised. The Panel has recommended that an FRF be conducted at VAFB prior to the first launch as a facility and crew certification. A bonus to such a test would be a partial insight into the 'twang' effect on the stack under the VAFB hold-down conditions."

The training of NASA/KSC and USAF personnel at VAFB will be achieved through the conduct of an FRF during the processing flow for the first launch at VAFB. The decision to conduct this FRF has been made and scheduling of the FRF and first launch is in process for the first quarter of 1986.

"Common ground support equipment interfacing with the space Shuttle vehicle requires special attention so that consistent functional design and such interface characteristics are rigidly maintained since loss of configuration commonality may occur due to KSC or VAFB programmatic requirements."

We believe that the proper efforts are being exerted to maintain GSE configuration control and commonality. The VAFB and KSC common and mod-common GSE is the responsibility of KSC for design, procurement and delivery to VAFB. Mod-common GSE is the KSC GSE which can be adapted for use at VAFB by design modifications. The common and mod-common GSE at VAFB constitute nearly all of the GSE at VAFB as well as most of the installed equipment which interfaces with the flight hardware at VAFB. KSC is also responsible for preparing and maintaining the OMD (Operational and Maintenance Document) and configuration control of this GSE.

APPENDIX 8. SHUTTLE CENTAUR

ASAP Recommendation

While acknowledging the fact that the issues are being addressed, the Panel urges that the matters of the safety waiver request and the interpretation of specifications be resolved with careful deliberation. The ability to make and incorporate significant design changes for Centaur G' within the time remaining to the planetary opportunity for Galileo is fast diminishing. With the major portion of the Centaur G' qualification test program remaining to be conducted, it would be highly desirable that the Centaur project staff be able to concentrate on insuring that the test requirements are met.

> NASA Response: Review and acceptance of waivers to the Headquarters NHB 1700.7A, "Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), are the responsibilities of the JSC Payload Safety Review Panel. It is the responsibility of the Centaur Program Office to determine that those specifications have been met or require a waiver.
>
> There has been concern over the redundancy and design margin of the Centaur Super*Zip separation system, and whether or not the design meets the NHB 1700.7A payload safety requirements. These concerns, of course, apply also to the IUS separation system which uses almost an identical design. Although both systems have completed qualification testing, new data, as a result of some pyrotechnic research work at Langley and margin determination testing at JPL for Galileo, indicate that the design margin may not be as great as originally thought. Additional testing is being performed at Langley to resolve this issue.
>
> With regard to changes, only those which are essential to make the Centaur G' perform its missions are being incorporated. The schedule is extremely tight. A hydrogen tank leak has been experienced and was attributed to a design oversight. A repair has been implemented on the test tank which has been successfully cycle and proof tested. Tank integrity was maintained throughout the 1.4 static loads test and reverification pressure cycle testing. The same fix has been completed on the flight G-prime tanks. The G-vehicle redesign has been baselined and the test vehicle will verify this redesign.
>
> Performance reserves, which were low, have now been reduced additionally by the required tank beef-up for the repair. The use of a portion of the Shuttle Program Manager's reserve is being pursued.

A special Phase II delta safety review was conducted at General Dynamics. Dr. Walter Williams recommended a review by JSC senior management following a special investigation of the Centaur Shuttle integration activity reported in a letter dated Feb. 6, 1985. The special safety review was chaired by Mr. Kohrs of JSC and included senior personnel on the board. No design changes resulted from the review which gives us confidence in the work being accomplished to date.

In terms of documenting the program's hazards based on the safety analysis and the rationale for risk acceptance, the contractor has not performed as well. Publication of the safety reports and the failure modes and effects analyses have been late. The Phase III safety review has been delayed several months because of inadequate preparations for the review. This is being given attention at GDC, and additional manpower is being allocated.

We are equally concerned with regard to the large amount of qualification testing that has to be done and are sensitive to ensuring that the program needs are satisfied by concentrating the appropriate personnel on testing activities. We fell behind the formal qualification largely due to late delivery of electronic piece parts, as the industry in general is experiencing, and due to late planning of hardware deliveries. To preserve schedule, preliminary system testing is being accomplished using prototype hardware. Production hardware will be installed following acceptance testing. Some will be installed at KSC. However, all production avionics should be installed before or during vehicle processing at Launch Complex 36. Qualification hardware is being built after the flight units to avoid disrupting vehicle flow.

Relative to abort mode operational constraints, we are working closely with JSC/RI to identify the various abort modes, the time available to dump propellants, residuals, vent rates, etc. The design driver to date appears to be the late systems TAL (Trans Atlantic Abort). To satisfy the safety constraints, in addition to the Orbiter landing weight c/g (center of gravity) management, we are implementing a vacuum inerting capability, which will reduce residuals to low levels. Testing and analysis are planned to verify this capability. We are also looking at inhibiting GH_2 venting during the critical time of reentry (Orbiter vent door opening to Mach 1) to preclude ingestion of GH_2 into the Orbiter OMS pod, lower mid fuselage, rudder speed brake and body flap).

APPENDIX 9. RADIOISOTOPE THERMOELECTRIC GENERATORS (RTG'S) FOR GALILEO AND ULYSSES MISSIONS

ASAP Recommendation

"The Panel endorses the proposal made by the ad hoc committee that addressed the issue to improve coordination among the organizations involved by appointing a 'single point of contact' on this subject for each organization. Further, the Panel endorses the recommendation to assign prime responsibility for obtaining flight clearance to the science mission center, Jet Propulsion Laboratory (JPL)."

> NASA Response: I believe that the appropriate contacts have been designated. Mr. R. Kohrs at JSC is responsible for coordinating the overall Shuttle reliability estimates and interfacing with the Interagency Nuclear Safety Review Panel. Mr. J. Cork of JPL has the responsibility for coordinating activities that will result in obtaining flight clearance. That is a full time assignment for Mr. Cork.
>
> Mr. Kohrs has been actively involved in revising the "Space Shuttle Data for Nuclear Safety Analysis" document, JSC 16087, to include the latest program data. STS failure modes and effects have been given further analysis, and the failure probability estimates are being reevaluated based upon our experience basis.
>
> It should be recalled that JPL coordinates with the DOE, who owns the RTG's, and who has the task to prepare the "Safety Analysis Report" (SAR), which describes the flight risk. The Interagency Nuclear Safety Review Panel (INSRP) prepares the "Safety Evaluation Report" (SER) after reviewing the SAR and then presents their independent evaluation of the risks. The NASA INSRP coordinator distributes the SER for a review by the NASA staff, collects the inputs, and prepares a report on the flight recommendation for the NASA Administrator which is forwarded to the White House staff for flight approval.
>
> More recent testing for the RTG fuel capsules causes us to be more optimistic about the capability of the RTG to survive severe overpressures that are being considered. The shock tube testing at Los Alamos has shown that it can withstand 1800 psi. There have been a number of meetings held in which INSRP and NASA participants have jointly met to review data and share planning. We are in the process of reviewing contingency planning.

APPENDIX 10. NASA AIRCRAFT OPERATIONS

ASAP Recommendation

The Aircraft Management Office, as the Agency focal point for all aircraft operations and related matters, should include, if practical, an aviation safety function. The NASA centers would benefit by a single reporting location at Headquarters.

> NASA Response: As the Panel pointed out, progress is being made in centralizing management of aircraft operations. Further, the Panel's specific recommendation that NASA Headquarters include aviation safety management and aircraft operations management in a single office has been accomplished. The Aircraft Management Office has been assigned the additional function of operational aviation safety and, in addition, this particular function has been strengthened by the hiring of two exceptionally qualified individuals in the areas of aviation safety and human factors engineering (human performance). Also as the Panel had recommended, the Centers now have a single reporting location in Headquarters. The Office of the Chief Engineer will continue aviation safety oversight to provide the appropriate audit function. The objective of these adjustments is to clearly separate implementation from oversight. Mr. Parmet met at Patrick Air Force Base in February with the Intercenter Aircraft Operations Panel and sat in on deliberations concerning the implementation of agencywide aircraft operations guidelines. The target date for publishing this document is September 1985.

Analysis of OSSA
Advanced Project Definition Activities

(Response to House Science and Technology Committee Request)

(March 1986)

Analysis of OSSA Advanced Project Definition Activities

In response to the Committee's request for a "critical review of all potential future missions now being studied or in advanced technology development," the Office of Space Science and Applications (OSSA) has reviewed these activities "with a view toward terminating work on those unlikely to be developed and concentrating efforts on more likely near-term new starts." We understand the Committee's concern and agree with the underlying premise that sizable investments in advanced technology development should only be made on activities that have a realistic chance of follow-through as a future flight project or shuttle payload. Having reviewed the advanced definition work on future projects underway during FY 1985, we believe that the overall pattern of OSSA investments is consistent with the offices' general scientific priorities arrived at after extensive deliberations over many years with our outside advisory committees and the division directors responsible for OSSA programs and does, in fact, concentrate on the more likely near-term starts.

Of the $45.5 million invested in such advanced technology development activities in FY 1985, $37.5 million or 82 percent of these funds were spent on future projects such as TOPEX, CRAF, AXAF, SOT, and GP-B which are all highest priority future initiatives for their respective scientific disciplines. Despite the current budgetary difficulties, OSSA management believes that all of these projects are scientifically important and that none of the scientific goals and objectives of these projects can be given up without major impacts to the future progress of these scientific disciplines. We believe that the program development and scientific planning mechanisms in place in OSSA provide the appropriate management tools to address the difficult choices required to balance across scientific disciplines and to trade off near-term versus long-term technology development requirements.

Overall stringency in the NASA budget and the intense competition for "new starts" across OSSA's diverse program responsibilities work together to assure that scarce advanced technology development funds are not expended on projects and activities of less than the highest scientific priority. For each of the scientific disciplines represented, these future project definition studies are taken very seriously because they are vital to the future scientific advancement of the field. Our program scientists understand that future projects have no chance of competing successfully in the OSSA or NASA budgets for "new start" status unless the project definition studies have been carried out with great care. The NASA project approval process focuses carefully on the status of advanced technology issues in project formulation, including a formal project "non-advocacy" review by independent technical experts. The results of these independent technical reviews are presented to the OSSA Associate Administrator and to the NASA Administrator.

The balance of this report provides a description of the OSSA program planning process and provides a brief capsule summary of future flight projects that are currently being funded in the OSSA budget.

Current Definition Activities

First, some background on NASA program and project management. The Hearth Committee Study on NASA Project Management (1981) stressed the need to carry out careful advanced planning for future programs because unresolved technical issues can result in increased technical risk and increased overall project costs, as was seen with the development of both the Infrared Astronomy Satellite and the Hubble Space Telescope. The ability to control project costs is crucial to overall program management and to OSSA's ability to initiate new flight projects.

The Hearth Committee found that inadequate definition prior to NASA budget decisions and external commitments was one of the most significant reasons for cost and schedule growth in several NASA projects. The study recommended that future NASA budgets should include greater definition funding. The study concluded that when projects were well defined, the estimates were relatively good, i.e. within 30% accuracy. An internal NASA study confirmed that when budget conditions permit a small investment for advanced definition prior to commitment we could generally realize significant benefits such as more effective project early planning, management and implementation.

New missions sometimes require the development of totally new technological capabilities--for example, the pointing accuracy and stability requirements of the Hubble Space Telescope; the advanced mirror technology for AXAF; the precision gyroscopes for GP-B; automation technology for planetary missions such as Voyager; and radiation hardened components for the Galileo spacecraft. Sometimes, as in the case of GP-B, an extended period of time is required for the development of this new technology and without early investments such projects would never become techcially feasible.

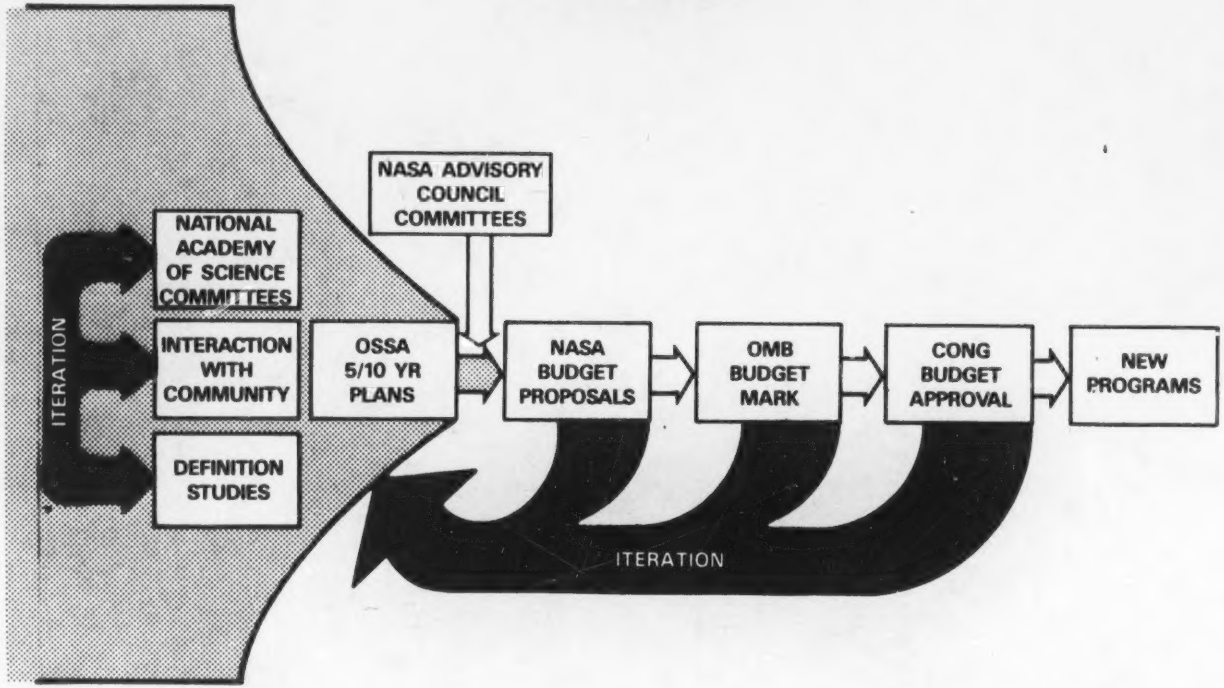
The OSSA planning process (shown schematically in figure 1) begins with an annual review by NASA management of proposed new projects for both the near-term and later years. The long-term goals of the program are developed in consultation with our advisory committees with the participation of NASA Centers and the scientific community. Their goals are translated into specific mission concepts which undergo feasibility (Phase A) and mission definition (Phase B) studies. Work on technology development is undertaken in support of thse studies as part of the process of preparing a mission for consideration as a new start. Our progress on these activities is regularly reviewed both internally and by the mission science working groups and our advisory committees. The advisory apparatus includes the Space Science and Space Applications Boards of the National Academy of Sciences and the Committees of NASA's Advisory Council, as well as leaders in industry, universities, and non-governmental research organizations. This planning process sets goals and policy on a continuing basis and also provides valuable feedback on our progress in fulfilling our overall mission goals.

The determination of appropriate levels of advanced technology support is made after careful consideration of potential new missions, both "near term" and "longer term". This determination by OSSA management incorporates studies and advice from the various NASA Advisory Committees, other input from the academic and scientific communities, evaluation of basic science requirements and opportunities resulting from previous missions, and other considerations such as the Agency's long range planning strategy. Typically, particularly for a major mission, 3-5 years of advanced study and technology work are needed. For cases where major new technology has to be invented, an appreciably longer period of work may be necessary.

Figure 1

OSSA

SPACE SCIENCE AND APPLICATIONS PLANNING


ITERATION
NATIONAL ACADEMY OF SCIENCE COMMITTEES
INTERACTION WITH COMMUNITY
DEFINITION STUDIES
OSSA 5/10 YR PLANS
NASA ADVISORY COUNCIL COMMITTEES
NASA BUDGET PROPOSALS
OMB BUDGET MARK
CONG BUDGET APPROVAL
NEW PROGRAMS
ITERATION

We are, in fact, currently concentrating our project definition efforts on the programs we believe will be started in the next three years or so, if approved through the budget process. They are the Ocean Topography Experiment (TOPEX), the Comet Rendezvous Asteroid Flyby Mission (CRAF), the Advanced X-Ray Astronomy Facility (AXAF), instrument research for the study of solar terrestrial physics and technology development and feasibility studies of Gravity Probe-B (GP-B). A list of funding in FY 1985 for advanced definition of future projects is provided in figure 2. These projects represent the highest priority future missions based on OSSA's consideration of many competing opportunities.

Ocean Topography Experiment (TOPEX)

TOPEX is our FY 1987 new start candidate.

TOPEX is expected to provide significant capabilities for observing the circulation of the oceans on a global basis. Its objectives will be to measure ocean surface topography over entire ocean basins for several years, to integrate those measurements with subsurface measurements and to use the results in models of the oceans' density fields to determine the oceans' general circulation and variability, and then to use the information from all these activities to develop an understanding of the nature of ocean dynamics. Such models can be used to calculate the heat transported by the oceans, to understand the interaction of currents with waves, and to test capabilities for predicting ocean circulation. The large-scale movement of water in the oceans has many significant consequences for life on Earth. For example, climate changes, fish production, commerce, waste disposal, and national security are all affected by ocean circulation and, in turn, affect daily life throughout the world.

Comet Rendezvous/Asteriod Flyby Mission (CRAF)

The CRAF mission will obtain detailed scientific data about two of the least studied objects in the solar system: comets and asteroids. This data will expand our basic knowledge about the solar system, its origin, earliest history, and evolution. The results of this mission could have a major impact on our understanding of important scientific questions including the nature and source of the material that formed the solar system; the physcial and chemical conditions in different parts of the original solar nebula; the origin of the Earth's atmosphere and the atmosphere of other planets; and the origin of life on Earth.

Advanced X-Ray Astrophysics Facility (AXAF)

AXAF will be a major space-based observatory that will penetrate deep into the universe to study the nature of cosmic violence using x-ray astronomy. X-ray observations are particularly sensitive to violent events and corresponding aftermaths. AXAF will address fundamental questions of astrophysics like the nature of stellar black holes and quasars, as well as the nature of the physical processes that take place in and between astronomical objects. AXAF will provide new observations and insights into the studies of stellar structure and evolution, large-scale galactic phenomena, active galaxies, clusters of galaxies, and cosmology. Lockheed and TRW are now working on competitive A-109 definition projects (Phase-B). Four science instruments have been selected for definition studies that are now underway. AXAF is the first priority major new program recommended by the Astronomy Survey Committee of the National Academy of Sciences.

Instrument Development For Collaborative Solar-Terrestrial Research

This initiative will provide instrumentation to study space physics processes in the near-Earth space environment and the interplanetary region known as geospace. Present plans provide for the utilization of flight opportunities presently under negotiation with the Japanese Institute of Space and Astronautical Sciences, the European Space Agency, and other payloads of opportunity. The overall thrust of this intiative will be to develop the capability to take measurements principally to investigate the solar interior, convection zone, corona of the Sun, and plasma flow and processes in the Earth's geotail.

Gravity Probe-B (GP-B)

GP-B is a possible future orbiting, cryogenic gyroscope experiment to test a fundamental concept of general relativity by measuring the precession of orbiting gyroscopes as they move through a gravitational field twisted by Earth's rotation (relativistic spin-spin coupling). Such "twisting" of space acts as a natural force that is to simple gravity what magnetism is to electricity. The structure of space and time will be investigated through the theory of general relativity. The relativity effect is very small and the experiment can only be carried out in space. The required measurement technology has been under study and definition since 1965, and many of the fundamental engineering problems to conduct the experiment have been resolved.

Solar Optical Telescope

ATD work on the Solar Optical Telescope (SOT) has been phased down to a reduced funding level for the balance of FY 1986 and no funding is being requested for FY 1987. Some low-level technical work will continue including assesments of low-cost alternatives for obtaining measurements that would contribute to the scientific objective of the Solar Optical Telescope.

Longer Term ATD

To maintain our capability to undertake new, more challenging missions in the longer term, a relatively small investment in longer term projects has historically been balanced against our heavier investments on near term missions. An early understanding of the major technological challenges on potential future misions can significantly reduce the overall uncertainties, risks, and costs of future missions, as well as contributing to the definition of more ambitious scientific investigations that may become feasible through the use of future technologies.

Summary

OSSA invests significant resources of time and money into the definition of future space projects that will contribute to the continuing advancement of our scientific and application goals. These investments are made in the development of advanced technologies and project definition studies to validate mission concepts and to reduce technical uncertainties and risks encountered in the initiation of more technically-challenging flight projects. The competition among scientific disciplines for "new start" opportunities is intense, involving major investments of time and money by NASA personnel, by contractor personnel involved in the project planning, and by the scientific investigators who participate in project formulation and implementation.

The NASA project approval process involves extensive interactions among Headquarters program office personnel, as well as the Comptroller's Office staff; with scientific and program management staffs at the NASA field centers; with scientific investigators in the universities; and with a large number of advisory committees who assess priorities for particular projects and develop broad program strategies for major fields of science. The ultimate decisions on program selection and priority are made by NASA's senior management. Because of overall budgetary constraints, success in obtaining "new start" approvals depends fundamentally upon the quality of the program planning and the reduction of technical uncertainties prior to project initiation. The funding of advanced technology and project definition studies in the OSSA budget is a major contributor to effective management of the science and applications program.

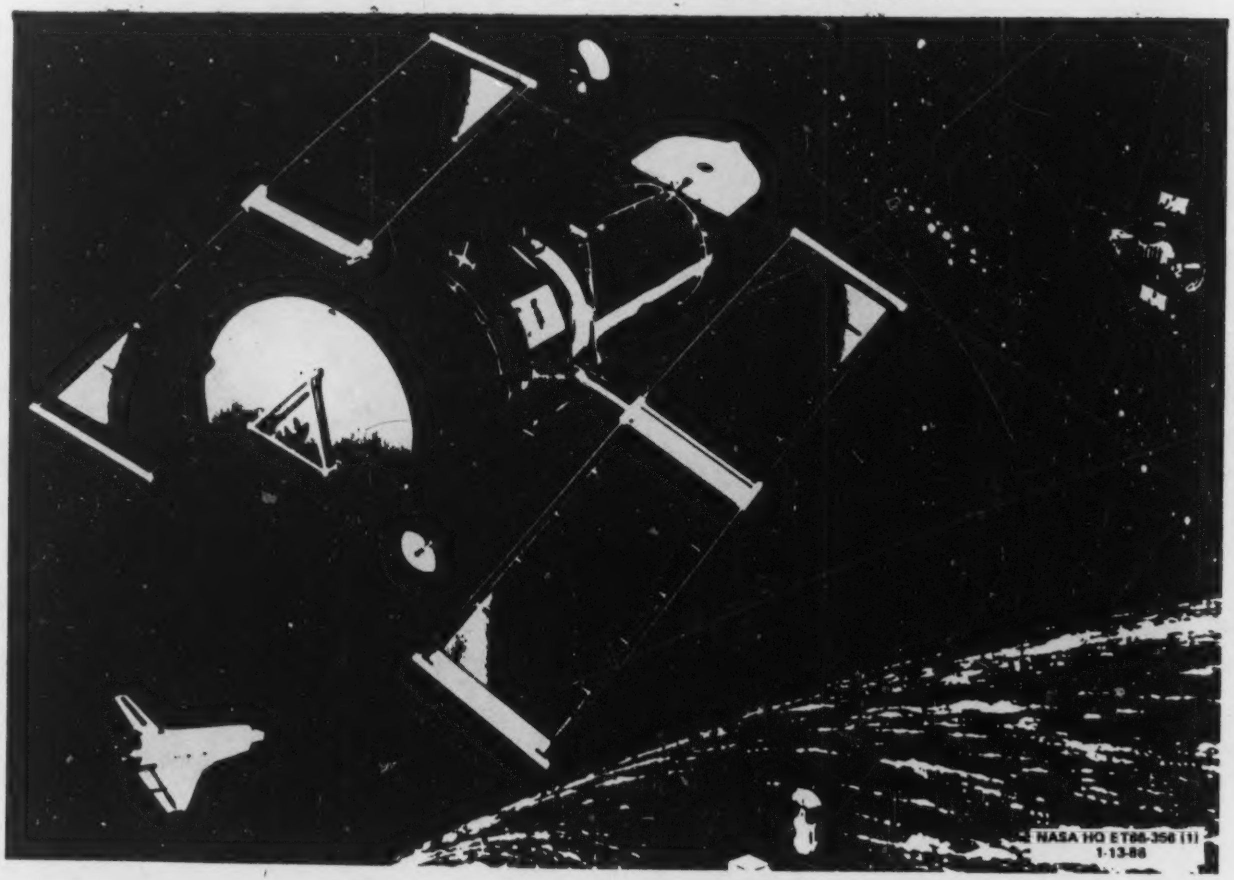
ANALYTICAL REVIEW OF HUBBLE SPACE TELESCOPE DEVELOPMENT

Prepared for the
Subcommittee on Space Science and Applications
of the
Committee on Science and Technology

U.S. House of Representatives

March 1986

HUBBLE SPACE TELESCOPE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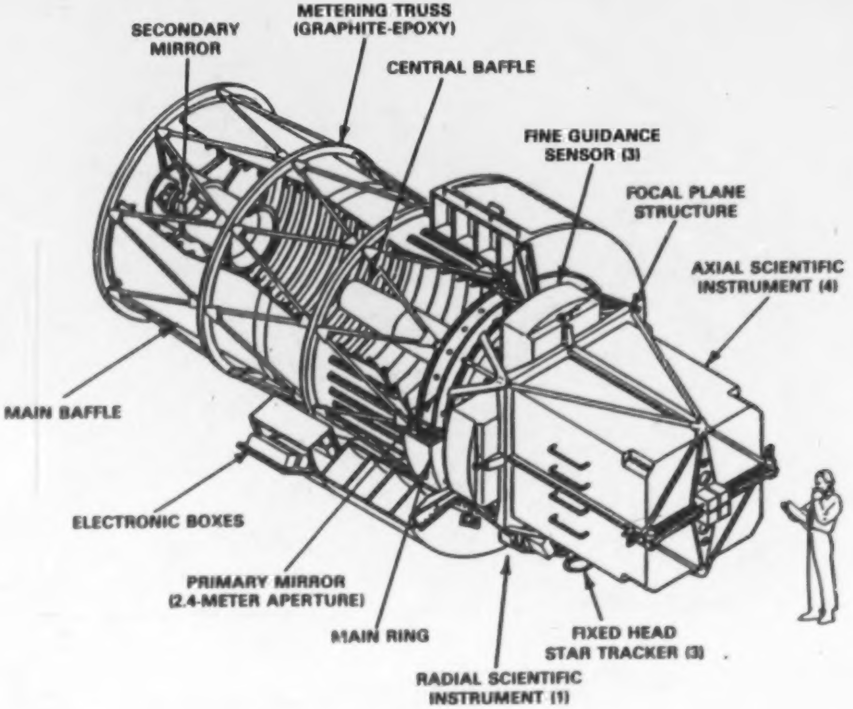
HST ASTRONOMICAL SYSTEMS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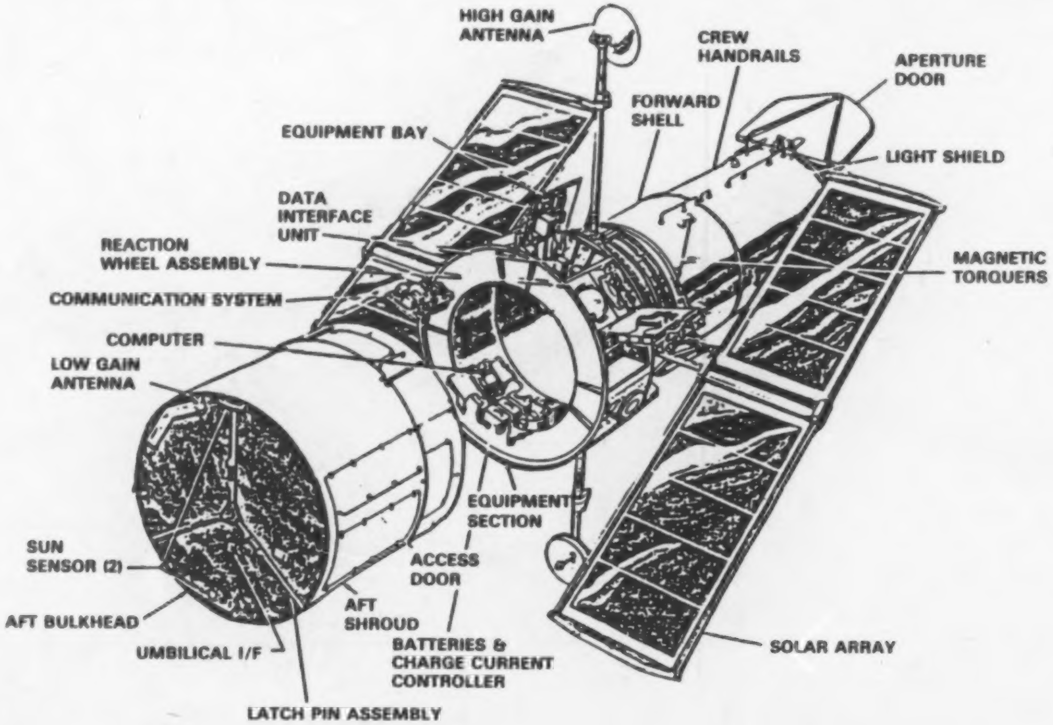
METERING TRUSS (GRAPHITE-EPOXY)
CENTRAL BAFFLE
FINE GUIDANCE SENSOR (3)
FOCAL PLANE STRUCTURE
AXIAL SCIENTIFIC INSTRUMENT (4)
MAIN BAFFLE
ELECTRONIC BOXES
PRIMARY MIRROR (2.4-METER APERTURE)
MAIN RING
RADIAL SCIENTIFIC INSTRUMENT (1)
FIXED HEAD STAR TRACKER (3)

HST SUPPORT SYSTEM MODULE (SSM)


HIGH GAIN ANTENNA
CREW HANDRAILS
APERTURE DOOR
FORWARD SHELL
EQUIPMENT BAY
LIGHT SHIELD
DATA INTERFACE UNIT
REACTION WHEEL ASSEMBLY
MAGNETIC TORQUERS
COMMUNICATION SYSTEM
COMPUTER
LOW GAIN ANTENNA
EQUIPMENT SECTION
SUN SENSOR (2)
ACCESS DOOR
AFT BULKHEAD
AFT SHROUD
UMBILICAL I/F
BATTERIES & CHARGE CURRENT CONTROLLER
SOLAR ARRAY
LATCH PIN ASSEMBLY

A. INTRODUCTION

1. Request by the Subcommittee

This report responds to the request of the Subcommittee on Space Science and Applications, Committee on Science and Technology, U.S. House of Representatives, that NASA review and analyze the Hubble Space Telescope (HST) Development Program, with the goal of providing an aid for the management of future large space science programs comparable to the HST, perhaps including the Space Station.

The request arose out of the Subcommittee's desire that lessons learned from early HST technical and management difficulties and subsequent management restructuring be analyzed and preserved for the benefit of future program management. The Subcommittee also was concerned about the risks involved in the final stages of HST development and about the ability of the telescope to meet its design requirements.

2. Other Reports and Testimony

The Subcommittee has followed closely the development of HST through a series of hearings and special reports. Of particular relevance to this analytical review of HST program management are the hearings held during February, 1983. In these hearings, NASA officials reported on technical and management problems that were impacting HST cost and schedule and they reported on NASA's review in depth of HST program management. The Subcommittee also was advised of NASA's management initiatives to ensure that a sound Space Telescope development program reaches completion. Subsequent hearings, in June, 1983, reported on the evolution of these initiatives into NASA program management actions.

The Subcommittee has requested a number of reports on topics related to HST development and operation. These include, in addition to this report, a report on Plans for Operation, Maintenance and Refurbishment (provided May 31, 1985) and a report on the Impact of the ST Science Institute on ST Development (being provided separately).

3. Objectives

The objectives of this report, set in response to the Subcommittee request, are to analyze HST program management and to derive lessons learned that will benefit NASA managers in future large space science development programs.

4. Contents

These are the contents of this report: First, we provide an Executive Summary. Next, we review the history of the HST to mid-program (late 1982), describing the status of the program at that time and commenting on the findings of the NASA review team. Then we describe current HST program management in detail, discussing the NASA management initiatives taken as a result of the HST review and commenting on the effects of these initiatives on the program. Finally, we condense the key issues for the management of future large space programs that emerge from this analysis.

5. Definitions

Discussions of management practices applied to the design, development, production and operation of large systems use several terms that appear to have straightforward, commonly used meanings, but which often do not. To enhance understanding of this report we define here some of the terms used in discussing the management issues of which we speak.

a. System Integration: A high level function, combining elements of system management and system engineering, that plans and oversees the assembly of components and subsystems from different sources into a total system. This function requires a top-down view of design, interface control, configuration management, assembly and verification (testing) of the total system.

b. System Management: Planning and control of a totally integrated engineering effort, leading to the design, development, production, test, evaluation and operation of a system.

c. System Engineering: The process through which the technical elements of system management are carried out, including these elements:

(1) Preliminary design,
(2) Allocation of requirements to design,
(3) Component, subsystem and system design,
(4) Configuration management,
(5) Interface control,
(6) Test planning and coordination,
(7) Operational testing, and
(8) Support of Operations.

d. Business Management: Another component of system management, complementing system engineering. Includes:

(1) Maintaining resource baselines,
(2) Planning project budgets,
(3) Coordinating inputs to higher level budgets, and
(4) Tracking resource expenditures, commitments and reserves.

B. EXECUTIVE SUMMARY

HST development at mid-program (late 1982) showed considerable progress in ground and flight segments. However, technical, business and management problems in the development of the Optical Telescope Assembly, and problems in systems engineering and systems management in the Headquarters and the Project Office, foretold schedule and cost problems in the HST program.

A NASA management review in depth in 1982-83 led to a number of management initiatives in 1983, which have been reported previously to the Subcommittee. The lessons learned from the NASA management review, from the implementation of management initiatives, and from the three years of experience since the initiatives were implemented, constitute valuable lessons that are applicable to other large space science development programs. The lessons learned in outline form are summarized below and in the following pages.

1. Organization

- Headquarters, like the field, should organize for system program management, including a "projectized" structure for managing top level issues.

- The Headquarters Program Office should be organized and staffed to play an active role in managing the program.

- The NASA Center Project Office should comprise a line organization, with dedicated staff responsive to the Project Manager.

2. Goals

- Top level performance specifications should be established early and checked for consistency and achievability at the lowest level of specification.

- Goals shared among major programs should be coordinated by the Headquarters.

3. Policy

- Priorities among major programs should be established clearly by NASA Headquarters.

- A penetrating technical assessment should be accomplished and accepted early in the program. Implied technical and cost risks must be recognized and accepted.

- Systems integration responsibility must be assigned early in the program, and the cost thereof recognized.

4. Headquarters Oversight

- Oversight must be dynamic, detailed and penetrating.

- Effective oversight requires adequate visibility into program details in real time. It requires some degree of automated management information and decision support, tailored to the program.

- Oversight requires a structured, formal decision making process.

5. User Community Involvement

- Role of users is major in two phases: requirements definition and final performance validation.

- Role of users during development should be tailored to program management needs. In this phase, some users also will be developers with potentially conflicting interests.

- Feedback from scientists is important in all phases.

- Users' perceptions of what is technically achievable should match reality.

- The Science community is a valuable source of talent that should be exploited by program management.

6. System Management

- Management must provide a clearly understood, integrated process for arriving at decisions.

- Planning, programming and budgeting systems must be realistic and dynamic.

- Analysis and projections of resource requirements must be realistic.

- Management must provide for anticipating problems and considering alternative solutions and their potential impacts.

- Management and organizational interfaces should be kept to a minimum.

- Management at different levels should be coordinated and complementary.

- A sound reserve management strategy is important.

- Quality and continuity of personnel is important.

- Ripple effects on associate contractors and subcontractors due to slow downs and changes should be minimized.

7. System Engineering

- This responsibility must be identified early.

- Adequate resources must be provided to support system engineering.

- It is extremely dangerous to neglect system engineering.

- Quality and continuity of personnel is important.

- Liaison among program segments is vital.

- Thorough integration of verification and test plans is needed.

- Timely accomplishment of technical audits and analyses is important.

- Tradeoffs between space and ground systems must be made early, during definition phase.

- Critical paths must be based upon technical difficulty and risk, as well as upon the need to integrate separate program elements.

- Sound technical baselines are essential for all other management activities.

- The system engineering function must identify and anticipate performance parameters that cannot be tested until on orbit, then systems must be designed to permit modifying untested parameters on orbit, and the cost of these modifications must be budgeted.

- The system engineering function must anticipate effects of actual operating environment, and,

    - Adequate models must be provided.

    - Possible sources of environmental stress must be identified.

    - Unknown effects of materials and techniques used in fabrication must be anticipated.

8. System Integration and Test

- Responsibility for this function must be established early.

- Cost of system integration, whether by contract or in house, must be faced at the outset.

- Test plans must be integrated for the total program.

- Test procedures must be understood and agreed to by all participants.

- Intermediate testing is important, but very inviting to cut.

- Management must anticipate that most "unknown unknowns" will appear during testing.

9. Planning

- Impact of complexity and technical difficulty must be accommodated in all planning.

- Development planning must include a full hierarchy of tests, from component functional to full system performance tests.

10. Equipment, Facilities and Logistics

- Special test equipment and special handling equipment needs must be anticipated. Any required original development, or major modification, of special test environments must be planned and contracted for as part of the overall system development effort.

- Adequate spares must be provided during the development phase, to sustain development in case of component failure.

11. Contractor Management

- Large, complex systems programs must accommodate a much more detailed and penetrating involvement by the Government project management staff than has been traditional.

- Government program managers must understand and accommodate individual companies' organizations, business practices, technical strengths and weaknesses, and corporate cultures.

- Contractors must have, or establish, sound technical and business management systems, to provide visibility and control of cost, schedule and performance.

C. HST DEVELOPMENT TO MID-PROGRAM

1. Development Status, Late 1982.

By late 1982, considerable progress had been made in the design and initial fabrication and assembly of HST components and subsystems, and in building the infrastructure to support observatory operations.

The ground facilities and software comprising the Mission Operation Ground System and the Science Operation Ground System were in design and development. Software coding had started. The ST Science Institute, established in 1981, was completing its staff recruiting and was preparing its facility for a mid-1983 opening. The Science Institute also was developing some elements of the Science Operation Ground System.

Fabrication and assembly of Science Instruments were nearing completion, and deliveries to NASA were under way. Plans were ready for integrated science instrument tests at Goddard Space Flight Center.

The Support System Module (SSM), a primary HST spacecraft subsystem which provides monitoring, control, data handling and power services to other subsystems, had been completely designed and was in the component fabrication phase.

A major milestone had been passed in the Optical Telescope Assembly (OTA) development with the delivery of the primary mirror. However, technical difficulties encountered in the development of the Fine Guidance Sensors were a major threat to the schedule. OTA structures, assembly, alignment and test had also encountered technical difficulties. One of the underlying causes of the engineering, schedule and cost problems that appeared in the OTA development was the unanticipated technical difficulty of designing and producing components and subsystems to achieve the extremely exacting performance standards of the HST design. Another underlying cause was serious technical management and business management problems at the contractor level.

NASA management review.

As a result of a number of technical and management problems which became evident late in 1982, it no longer appeared possible to complete OTA integration and test and ST integration and test, and to launch HST by the first half of 1985. Therefore, NASA conducted a major, comprehensive review of HST management at all levels. A number of technical and management problems were highlighted by this review, including Headquarters management, project management by NASA and its contractors, and business management at all levels. Management barriers were discovered which were inhibiting technical progress. Weakness was found in decision support capability at all levels, primarily a result of lack of visibility into program issues as required to anticipate problems. These findings provided the basis for a number of NASA management actions which were implemented early in 1983, as previously reported to the Subcommittee.

Since the specific problems uncovered during the 1982-83 NASA review have been reported previously, they are not repeated explicitly here. Instead, we now turn to the status of HST program management today, which reflects the management changes that followed the 1983 NASA Headquarters review of the HST program. We shall discuss the objectives of those management changes, the specific actions taken to address the identified problems, and results.

D. HST PROGRAM MANAGEMENT TODAY

We have reviewed the genesis of this report, the progress of the Space Telescope to mid-program, and NASA's top level review of program management to that point. Now we shall describe the organization, policies and procedures in Space Telescope program management that were put into effect as a result of the review, discuss their effects upon the system development, and derive lessons learned for the management of future large space science projects.

The analysis that follows is structured around the three principal levels of NASA organization (Headquarters, Center, and Project Office), and the contractor organizations.

1. Headquarters

The comprehensive NASA review of the status of the Space Telescope development program, and of the management of the program, resulted in recognition of the need for a number of management improvements at NASA Headquarters. We discuss these now in terms of six elements of Headquarters management: Organization, Goals, Policies, Oversight of Project Management, User Community Involvement, and System Management.

a. Organization

The HST program organization is complex, involving two NASA Centers, two major contractors and a number of smaller associate contractors and subcontractors who are engaged in development and operation of the HST. Two other NASA Centers and their contractors will perform launch preparations, launch and deployment of HST. This organizational complexity creates a number of technical and management interfaces. These complex interfaces, in turn, demand strong system management oversight from NASA Headquarters during all phases of the program.

A fundamental change was made in NASA Headquarters management of the Space Telescope program early in 1983. The role of the Headquarters Program Director was enhanced by his designation as director of the new Space Telescope Development Division. The Space Telescope Development Division was provided with an expanded, dedicated staff, comprising specialists in technical development, business management and system management. Staff size was increased and efforts were made to reduce turnover and maintain continuity. The job of this staff was to improve Headquarters management oversight and penetration of the Space Telescope program, and, thereby, to enable the Headquarters more effectively to control the progress of the Space Telescope development program.

Improvements in oversight of the HST project management by the NASA Headquarters included better visibility of technical and resource issues, and, as a result, maintenance of good technical, schedule, and cost baselines upon which to judge program progress. The Headquarters staff assisted the Program Director in exercising authority on critical decision issues on the HST program. This increase of involvement in program management on the part of Headquarters was intended to help the Project Office and contractors keep up with the Agency planning and budgeting cycle, and to help them avoid problems through early action on financial and budget plans. Finally, increased Headquarters involvement was intended to insure that top level HST mission performance requirements were clearly articulated early enough, and checked for consistency ("flowed down") with lower levels, to support the validation of subsystem design and development.

b. Goals

The NASA review of the Space Telescope program management brought out the need for specifying clearly the Agency goals for a particular large science mission development program. Once the overall science mission objectives are determined, through consultation among Agency planners and a broad representation of the scientific community, specific top level performance objectives must be stated. The purpose of this top level requirements statement (referred to hereafter as Level 1 requirements) is to provide the definitive technical reference upon which all lower level performance requirements, down to the component design level, are based.

When the Agency states its top level system performance requirements, it also must state procedures and timetables for processing (flowing down) requirements to lower levels of design detail. This process should be carried out early in the program, to insure the integrity and traceability of the top-down design process. Another reason for carrying out this requirements flow-down early is that it is needed to answer questions about the achievability of top level performance goals. This must be considered in terms of hardware and software that are feasible to build within the state of the art. Still another reason for early performance of a requirements flow-down is that it is essential to the assembly and verification phase of system development, when components are assembled and integrated into subsystems, systems, and eventually into an integrated space system. In the case of the Space Telescope, this process was delayed somewhat. For these reasons, the requirements analysis was a primary concern of the newly formed Space Telescope Development Division, and its initiation was one of the first management steps taken by the Division.

Another task that the Agency must address early in a major program is defining the relationships among the goals of a number of major programs. In the case of the Space Telescope, the program goals of the Space Shuttle and TDRS programs were tied closely to those of the telescope from the outset. As the telescope program matured, its goals also became linked conceptually to those of the Space Station, because of the potential for orbital maintenance and repair in the Space Station. Since all of these major programs compete for resources, as well as contributing to each other's mission, the relationships among the agencies' goals for the missions had to be stated clearly.

This point about the Agency-level coordination of program goals is illustrated further by the case of the "Great Observatories," the planned family of great astrophysics observatories, of which HST is one. The other members of this family are the proposed Advanced X-ray Astrophysics Facility, the Gamma Ray Observatory, and the proposed Space Infrared Telescope Facility.

Traditionally, in astrophysics research, each science mission would require separate and independent facilities, with separate operators, and would serve separate scientific communities. However, it is increasingly being recognized that there is synergism among these large, space based observatory concepts. First, there is considerable complementarity in their spectral regimes. In addition, there is much commonality in their need for spares, ground systems, operational software and training. Finally, in the approaching era of on-orbit servicing, there should be much commonality in tools, servicing processes and service facilities. These considerations led to a NASA policy goal to do integrated planning for the Great Observatories, in order to obtain the most science return for Agency resource expenditures.

c. Policies

In addition to broad Agency goals for science missions, NASA establishes specific policies and practices for carrying out each development program. Each program must carry a priority relative to other Agency programs, and specific resource and schedule constraints must be derived from these priorities. In the case of the Space Telescope, the mid-program review of program management revealed a need for more specific focus upon the Space Telescope as the prime NASA space science program, and for greater emphasis upon Headquarters program management oversight of the telescope. The formation of the Space Telescope Development Division, and the other management actions discussed in this report, were direct responses to these top level policy judgments.

The international nature of the HST program provided another lesson learned for NASA management. The multiple layers of foreign government and foreign contractor management added to the already considerable complexity of the Space Telescope management structure. Enforcement of management discipline in such matters as interface control, configuration management, test planning, and mechanical and electrical integration and testing was made more difficult by country-to-country agreements and foreign contracting practices that lie outside the traditional bounds of U.S. systems management practices.

Another important policy lesson learned in the Space Telescope program concerns the need for an accurate, top level assessment of the technical difficulty of a new program start, and the need for an Agency commitment to solving the technical problems. This assessment must include an understanding of the state of the generally available technology, as well as an appreciation of the complexity of the particular design concept being considered. Implicit in the appreciation of technical difficulty is an acceptance of risk. The risk to which program management is exposed because of lack of understanding of the technical difficulties includes not only the risk of technical failure, but also the risk of high cost in resources needed to overcome technical difficulties. In the case of the Space Telescope program, an early lack of appreciation of the technical difficulty and conceptual complexity of the telescope caused an unexpected exposure to cost and schedule risk.

Operating philosophy provides another policy lesson learned from the Space Telescope experience. A realistic and workable division of effort between Government and contract effort should be made early in the program. In the Space Telescope program, an early effort to hold down Project Office size, combined with a decision to do system integration and system engineering in house, led to inconsistency between commitments and resources.

Another policy issue that came to the surface during the HST program was that of the organizational placement within the NASA Headquarters of large flight programs, such as the Space Telescope. Specifically, the placement of flight program responsibility in a division whose basic interest and responsibility is in science and science projects causes difficulty, as the resource needs of the flight program compete with those of smaller science projects. In the case of the early Space Telescope program, this competition for funds was treated as a zero sum competition. This resulted in resource restrictions for HST that led to some self-defeating management decisions. These included limiting development spares, eliminating some component redundancy, and selectively reducing parts quality. These efforts to save resources early in the program led to problems later in the development that were corrected only at considerable cost.

A final policy issue from the HST experience is that of the inconsistency between the system-oriented organization that is desirable in a large flight program and the science-oriented and administration-oriented organization of the NASA Headquarters and the NASA Centers. We have referred to the top level goals and policy integration required in the HST program among such diverse elements as the HST, the TDRS, the STS and the Ground/Space Tracking and Data Network. We also referred to the evolution of the Great Observatories policy initiative. These major enterprises require the same total system orientation at the top of the Agency as they do at the working levels. However, the organization of the Headquarters and Centers, and the working relationships between the Headquarters and Centers, are such that only in the office of the Administrator is there convergence to a single point of view on priorities and resources. The lesson learned from this experience is that a great deal of coordination is required among the affected Associate Administrators and appropriate NASA Centers before issues are raised to the Administrator.

d. Oversight of Project Management

The Space Telescope program had, by late 1982, encountered serious problems in technical development, system engineering, and business and financial management. These problems were found to be due in large measure to a lack of direct, detailed and forceful oversight of and involvement in the management of the HST program by NASA Headquarters. The establishment of the Space Telescope Development Division enabled the Headquarters Program Director to take timely and effective action on substantial program issues. In particular, he was able to discern and focus management attention on financial management actions that were required to mesh with the annual agency budget cycle. The key to this capability was Headquarters financial detail on the HST development.

Thus, the need for Headquarters oversight of program management was a key lesson learned from the Space Telescope. The Headquarters must maintain visibility on both technical and resource issues and must be involved in detail in project activity, in order to anticipate problems and to provide timely solutions when Headquarters actions are needed. Fundamental to maintaining this visibility is the capability to display and process management information and to support the decision making process through consideration of alternatives and contingencies.

To supply this capability, the Space Telescope Development Division established the Space Telescope Decision Support System (STDSS), comprising an automated management information and planning system. The purpose of this system is to keep NASA Headquarters managers informed on detailed technical performance of the Space Telescope, and on the cost and schedule ramifications of alternative solutions to problems that arise. The STDSS provides this information on a time scale consistent with real time management, and consistent with Agency budgeting and planning activities. The STDSS is designed to provide common data bases and common planning frameworks for all participants in Space Telescope management, thereby enhancing the timely flow of information needed for effective management. This system is in use throughout the Space Telescope program management structure, and is being considered for Agency-wide use in NASA.

Headquarters program management oversight also must include a mechanism for decisions on critical program issues. In the case of the Space Telescope, critical decision authority was reserved for the Headquarters Program Director, and formal procedures were set up for obtaining these decisions. The Space Telescope Development Division established a Critical Decision Issue format to implement this function. Critical decision authority was exercised, and continues to be exercised, over issues involving the Space Telescope resource allocation, technical development, and mission capability.

Critical decision issues on resource allocation have included such matters as these:

- Commitment of Headquarters reserves to provide spares for development of the Optical Telescope Assembly, thus offsetting an earlier program restriction that had inhibited subsystem development.

- Authorization for continued operation of a special development facility at Lockheed Missiles and Space Company, the Hardware/Software Integration Facility. The facility was scheduled to close after the development phase, but was retained for operation during assembly and verification. It proved to be a key factor in the integration of flight software, development of test software, and trouble shooting and functional testing of electronics components.

- Authorization to establish a second shift to accommodate the delayed bakeout of the Support Systems Module during the initial phases of SSM assembly and verification, thereby avoiding disruption of schedule during this phase.

Critical decision issues on technical development have included:

- Redesign of solar cell electric power sources to accommodate growth in system power requirements and to reduce uncertainty about long-term power margins.

- Selection of the "light pipe" approach for ultraviolet flooding of the Wide Field/Planetary Camera (WF/PC) charge coupled device sensors to stabilize their calibration. This decision rejected a plan for pointing the telescope at the sun, an approach that would have required manual control intervention to overcome inherent HST safe modes and would have put the spacecraft outside of its thermal design envelope.

- Redesign of the latches securing the Wide Field/Planetary Camera to the telescope structure, to eliminate uncertainty about meeting structural stiffness and thermal design requirements.

- Division between ground and spacecraft computers of the data processing load for calculating the optical distortion corrections needed in determining positional relationships between guide stars and the telescope target.

Critical decisions on mission capability issues included:

- Deletion of the requirement for return to earth for refurbishment and elimination of the associated ground support. This action was based upon the evolving capability to change, repair and upgrade HST components and subsystems in orbit from the STS shuttle (and eventually the Space Station).

- Phasing of capabilities for on-orbit maintenance and repair, to achieve optimum capability for each period of early HST operations, consistent with available resources.

- Statement of the objectives and scope of the System Compatibility Test, the goal of which is to provide adequate confidence that the HST performance in orbit will meet the top level science mission performance requirements.

Finally, another step taken early by the new NASA Headquarters Space Telescope management organization to improve Headquarters oversight of program management was establishment of a schedule for additional, more formal reviews with the field Project Manager at Marshall Space Flight Center. The purpose of these reviews was to keep the Headquarters better informed on progress, problems and the correlation between development progress and resource allocation. These reviews were an important information source supporting the previously described initiatives for Headquarters oversight, decision support, and critical decision making.

e. User Community Involvement

Experience with user involvement in the Space Telescope program taught that this involvement must continue throughout all phases of the program. During the requirements definition phase, user inputs are needed to insure that science mission needs are scientifically sound, that performance goals represent realistically the underlying science mission needs, and that verification requirements during test and evaluation are meaningful in terms of the basic science mission. In the concept formulation phase, user inputs help in making tradeoffs between cost and performance, and in defining operational concepts and procedures. During the development and test phases, user inputs are needed in evaluating intermediate test results and planning for system level tests. User inputs are particularly valuable for planning sustaining operations and capability enhancements that may be desired after a period of initial operations. Finally, user inputs are essential in planning and carrying out operational evaluations. The users supply meaningful mission success criteria, and help evaluate operational test results in terms of the basic science mission performance criteria.

These considerations of user involvement raise some questions of degree and appropriateness that are not easy to answer. Once the science mission requirements are specified and agreed upon, the basic job is, ultimately, the development of the system within the technical and resource guidelines that are provided. While the users are major contributors at each state of program development, their involvement must be established on the basis of the program management requirements. It is not always clear to what extent user's interests should prevail at various stages of a program's development. The users are motivated to optimize system performance, not necessarily to accommodate the real-world tradeoffs between cost and the last increment of performance. One further point that confuses the issue is that the users may, at some point in the program, be put into a conflict of interest between their roles as developers of a system component (e.g. an instrument) and as users/advisors on the program development.

It is not clear whether in the specific case of HST the response of management to user interests was appropriate, that is, not overreactive or underreactive. What is clear is that there is an appropriate level of user involvement at each state of the program. It is a challenge to management to determine these levels of involvement, and to arrange modalities for their implementation.

Having made the point about needing to balance users' interests against program management's interest, we turn specifically to NASA's review of Space Telescope program management. This review showed that the eventual users of Space Telescope, the scientists, were less than optimally involved in the development, integration, and evaluation of the observatory. A series of initiatives was taken by NASA Headquarters to remedy this situation.

First, a number of special studies and analyses were undertaken, at the cost of several million dollars over several years, to resolve questions by the astronomy community about the effect of certain component and subsystem design characteristics upon the predicted performance of the Space Telescope observatory. These studies covered such topics as the design of the Fine Guidance Sensors, the design of latches for attaching science instruments to the telescope, the behavior of major structures under the cyclic thermal loads of orbital operations, and the problem of particulate contamination of the primary mirror during the long period of integration of the Space Telescope subsystems. These studies played a great part in laying to rest fears about the ultimate system level performance of the Space Telescope.

Another initiative to involve the science community in the Space Telescope development and evaluation was a continuing series of consultations with advisory groups. The Space Telescope Observatory Performance Assessment Team met frequently, and addressed itself specifically to the actual and projected performance of the Space Telescope as an observatory system. The Science Working Group provided a continuing perspective on the use of Space Telescope for specific scientific observations and studies.

In another initiative, the Director of the Space Telescope Development Division convened an ad hoc study group to assess the soundness of the design and operational approach for the Space Telescope ground control and science data exploitation systems. This group, from outside of NASA, was familiar with the design requirements of space systems of size and complexity comparable to those to the HST. Their conclusions affirmed the general soundness of the approach being taken in the development of HST.

Finally, the management of the Space Telescope Science Institute was assessed by the National Association of Program Administrators, to insure that it was following sound management practices in carrying out its charter on behalf of the astronomy community.

f. System Management

The Space Telescope program taught some valuable lessons in both business management and technical management at the Headquarters level. Management of reserves at Headquarters, through the exercise of the critical issue decision authority, was an important tool in responding to development program problems. Realistic cost estimates are an important part of the management of reserves. The entire process relies, of course, upon the visibility into program costs provided by an accurate and timely management information system.

At mid-program, the Space Telescope program showed weakness in the coupling between funding needs at the Project level and the budget planning cycle that drove actions at the Headquarters levels. The difficulty was resolved by providing the Headquarters with better visibility on lower level business management activity and earlier warning of the need for Agency budget action during the annual planning and appropriations cycle.

Technical management practices on the Space Telescope program provide some valuable lessons learned for NASA Headquarters. First, the assignment of project responsibility and establishment of a program management organization must be realistic, considering the size and complexity of the program. In the Space Telescope program, a complex technical task was assigned to a large and complex program organization, involving many different Government and contractor offices. The initial Headquarters Program Office was not sized or organized to handle this challenge.

A final critical management lesson learned on the Space Telescope concerned the contract structure. The responsibility for system integration must be spelled out clearly, including the physical integration function and the overall management of interfaces, error budgets, system level analyses, and integrated test planning and execution. If prime integrating responsibility at the system level is to be assigned to a contractor, the required authority over associate and subcontractors must be contained in the contract.

In the case of Space Telescope, no prime integrating contractor was selected to maintain overall interface and coordination control. Therefore, the responsibility fell upon the Project Office. However, the Project Office had not been authorized enough manpower initially to fulfill this responsibility. The deficiency had to be overcome later by a modification to the development contract that provided additional contract system engineering support to the top level integration tasks.

2. NASA Center Management

We turn next to system program management at the NASA Center level. These lessons involved resource management at the Center level, and support by the Center to the Project Office.

Personnel support of a development program can involve both dedicated and matrixed resources. In the case of the Space Telescope, the review of the program at mid-point showed the need at the Marshall Space Flight Center for a more substantial system engineering component in the Project Office, dedicated and functionally responsible to the Project Manager.

This was provided. At the same time, the matrix component of system engineering support also was enhanced from the science and engineering laboratories.

Direct support of a Project Office by the Center is scaled by internal Center priorities. When the Space Telescope ran into development difficulties, it was necessary to shift priorities and to provide the Space Telescope with additional support funding and personnel. As the program developed, and as the technical difficulty became better appreciated, additional skills and additional quantities of people had to be assigned to the Space Telescope project.

3. Project Office Management

In addition to the changes in program management actions at NASA Headquarters and in the Marshall Space Flight Center Headquarters, a number of changes occurred in the Project Office, as a result of the findings of the NASA review of Space Telescope program management.

a. Project Office Organization

As we have seen, the staff assigned to the Space Telescope project was enhanced substantially. A fundamental lesson learned concerned both the number and quality of personnel assigned to the project. On the Space Telescope program, quantity of personnel was an issue, and the quality of personnel later became one.

Continuity of assignment ranks in importance with personnel quantity and quality issues. One of the findings of NASA's review of the Space Telescope was that turnover of personnel at all organizational levels probably contributed to failure to detect and correct problems earlier.

Project Office morale proved to be an important consideration in HST project management too. During the early phases of the program, competition for funds led to some management decisions that limited progress of development and led to a feeling of helplessness on the part of Project Office personnel. Another factor contributing to frustration in the Project Office was manpower restrictions placed upon the office early in the program, in part to protect advanced technologies.

As a result of these morale problems, some of the better people began to drift away from the Project Office. At this point, quality of people on the program started to become a problem. The authorization of additional personnel to enhance the ability of the Project Office to oversee project elements thus contributed to better morale and better quality, as well as to improved management effectiveness.

b. Project Office Oversight of Project Elements

As was true at the Headquarters level, the Project Office needed mechanisms to support problem detection and decision making. These mechanisms included means to provide visibility on technical and resource issues, such as better management information systems, greater on-site involvement by the Project Office, and better decision-making processes.

Improvements in management information modalities constituted a major initiative to improve efficiency in the HST Project Office, as well as in the NASA Headquarters. The Project Office at Marshall Space Flight Center established an improved management information system, interfacing with the Space Telescope Decision Support System. This contributed to improved visibility on current issues, enhancing management at all levels. The improved information processing capability in the Project Office also enhanced the office's capability to formulate critical decision issues for timely resolution and assistance at higher management levels. The net effect was improved visibility on key issues and improved ability to bring critical issues to Headquarters in time for resolution.

In-plant presence of Project Office people at major contractor facilities was strengthened by the formation of Optical Telescope Assembly and Support Systems Module resident management offices, with direct responsibility in the management of the projects. The formation of these offices represented a level of penetration into contractor activities below the subsystem level that was beyond the usual NASA experience. This level of penetration and visibility into the details of program management was found to be necessary because of the complexity of the Space Telescope design, because of the technical difficulty of its development, and because of the complexity of the program organization.

Formal procedures for handling critical decision issues in the Project Office were established to respond to the Headquarters exercise of critical issue decision authority. Through these procedures issues were defined, pertinent information gathered, alternatives developed, and recommendations formulated for higher level decisions.

c. System Engineering

System engineering got particular emphasis in the enhancement of the Project Office organization. A senior deputy was appointed to assist the Project Manager by managing all aspects of system engineering. As we have seen, additional staff was assigned directly in the Project Office to support system engineering, and additional staff was made available through matrixing from the laboratories. Further enhancement of system engineering capability was obtained through contractor support. A system engineering group was formed in the Lockheed Missiles and Space Company and was dedicated to the system engineering task.

The purpose of these enhancements of the Project Office was to improve system engineering and system integration. Provision of additional personnel resources offsets the lack of a prime integrating contractor and the initial understaffing of the Project Office. A key objective of this initiative was to improve liaison and interactions among associate and subcontractors by establishing a disciplined interface control framework. This, in turn, improved interface control across organizational boundaries, often required in the production of components for integration into subsystems, by providing formal structure and procedures. Another objective was to insure that test plans and procedures were coordinated and integrated.

The project systems engineering staff performs many functions. A few of those that were shown by the Space Telescope experience to be of particular importance will be noted here. The first of these functions is the requirements flowdown analysis, already discussed. This process got started late for Space Telescope. Another important systems analysis function is preparation for system level tests. Testing needs and testing capability must be established, and system level tests must be integrated with component functional tests in the interest of efficiency. In Space Telescope, this integration turned out to be a difficult job requiring coordination of the inputs of many associate contractors, on a tight time schedule, when they had many other tasks to do.

Problem identification and analysis is a systems engineering function that would have benefited the development of the Space Telescope Optical Telescope Assembly, if the function had been advanced further early in the program. Problem identification is the first step in the critical process of decision formulation and decision making, the strengthening of which was a first priority of both the Space Telescope Development Division and the Project Office.

Other systems engineering functions which turned out to be of great importance to the Space Telescope were interface control and change control. Because of the many associate contractors developing many different subsystems, the technical and management interfaces were exceptionally complex. Formal procedures were essential for coordinating all these efforts. A particularly demanding aspect of this systems engineering function was the need to provide visibility, for all of the associated subsystem developers, on the potential future impacts of design changes.

A major source of difficulty in the technical development of HST by mid-program was the failure in some key subsystem projects to establish and maintain a good technical baseline. A prime goal of the Project Office was to improve its capability to validate a technical rebaselining by prime contractors. This capability was made possible by additional personnel, improved focus on system engineering and by increased penetration into the details of contractor engineering development.

Other difficulties that the Project Office had to overcome were inadequacy of models for analyzing the effects of environments, stress and performance upon HST subsystems, and lack of capability to analyze performance and identify problems. Because of these deficiencies, some necessary audits and analyses were deferred or not anticipated in time. Late detection of problems and technical surprises resulted. The Project Office again addressed this problem by improving visibility into the details of contractor engineering management. They also took steps to insure that all critical system performance parameters were being quantified and tracked. These actions all reflected an increased emphasis on system engineering in the HST project.

A final example of actions needed by the Project Office to effect improvements in engineering development was in intermediate testing. Early program decisions to eliminate certain systems level environmental and functional tests during intermediate phases of subsystem integration delayed the detection of system level problems to later program phases. This increased the risk of delays as technical problems arose late in the integration of HST. After the NASA review of the HST program, Systems Compatibility Tests were added to the assembly and verification program to insure that adequate systems level testing was accomplished.

d. System Integration

The system integration function is a key element of the management of a major system program. System integration requires the broadest view of present and future development issues and the broadest view of relationships among program components. The system integrator must control all system-level interactions among subsystems, including both management coordination among different contractors and technical interfaces involving hardware and information flows. Not only must the system integrator control current interactions, he must plan and forecast future impacts, as designs and changes propagate across interfaces and affect the design and fabrication activities of the associate contractors.

A key aspect of system integration planning for which management must be prepared is the cost. If the Government is the integrator, the costs may or may not be visible explicitly. If a prime integrating contractor is to be selected, the costs must be recognized explicitly and written into the contract.

e. Development Planning

The Space Telescope program provided many good lessons learned in development planning, the long range view that must be taken of the life cycle of a program. The first lesson involves the analysis of complexity. The Project Office, early in the program, must understand the technical complexity of the proposed concept, must adapt the program plan to the technical challenge and must advise all parties, higher and lower in the program organization, of the impact of technical complexity. It is particularly important that they assess realistically the impact of technical complexity upon cost and schedule.

The Space Telescope program also showed the need for good simulations and models in all program phases. These are needed to provide checks of the design and development processes and to supplement and verify testing.

Development planning must anticipate the need to develop advanced test environments to match the technical complexity of the system concept. These test environments can become advanced development programs of considerable complexity in their own right, comprising a development program within a development program. This increases the overall risk and contributes to schedule delays. In the Space Telescope program, such test environment developments did impact an the critical path. Specific examples included OTA special test equipment and the Spacecraft Automated Test System.

The Space Telescope program taught that the flow down of technical performance requirements should be accomplished early, in order to provide a frame of reference for judging the progress of design, development, assembly, and testing.

Finally, development planning should establish a hierarchy of development, system-level, and operational tests early enough in the program for all developers to appreciate the impact of test requirements upon their subsystems developments.

f. Business Management

Space Telescope experience showed the need for sound business management at the project level. A prime requirement was for sound cost analysis based on sound technical analysis. Indeed, a basic weakness early in the Space Telescope program, as revealed by NASA's review, was a lack of such a technical foundation upon which to base financial plans. Establishment of good technical baselines was thus a prime goal of the project management. Doing this made it possible to make realistic spending and budget projections. These, in turn, made it possible to coordinate Space Telescope funding needs with the top level NASA budget cycle. In addition, good project financial forecasts made it possible to manage reserves better at the Headquarters levels.

A related point, arguing for good technical baselines, is that of the credibility of the estimates that support stated resource requirements. Since the submission of budget requirements to higher organizational levels is basically a competitive process, it is essential that the requests be backed up by credible technical baselines.

Another lesson learned from Space Telescope project management was the need to provide an even flow of work and resources, based upon accurate technical and financial forecasts. Slowdowns and curtailment of effort, brought about by financial limitations, which in turn were brought about by inadequate forecasts, caused added program cost over the long run. Slowdowns and interruptions were particularly damaging for smaller companies, who lacked the resource and business bases to ride out work and funding perturbations as well as their larger associates could.

Another area in which management improvements were carried out as a result of NASA's review of Space Telescope was in programming and budgeting at the project level. Elements of the project that had encountered cost and schedule problems were rebaselined, and new cost and schedule estimates were developed. The capabilities to monitor these baselines more easily and to respond to difficulties was enhanced by the organizational changes in the Project Office. They also were enhanced by the presence of NASA people at the major contractors' facilities. This presence afforded a much higher degree of awareness of the day to day status of subsystem developments, and provided an early warning system to flag potential deviations from plan. Thus, the Project Office was in a much better position to plan and to adjust financial and technical plans in near real time. They were also in a much better position to conform to the Agency budget and planning cycle.

NASA's review of Space Telescope program management brought to light a need to improve the operation of the planning, programming and budgeting system. Procedures were established to produce planning documents and budgets that were accurate and timely and which fit into the annual Agency budget cycle. NASA Headquarters was enabled thereby to become aware of financial problems in time to meet the schedule for annual agency budget inputs. The HST Project Office took action to insure that contractors maintained adequate financial baselines. The presence of Project Office representatives in the contractor's plants brought about a major improvement in these financial baselines.

The key to making better financial forecasts proved to be better technical estimates. These were made difficult by the unexpected technical difficulty of developing some HST elements. Even after solving this problem, the Project Office found other problems that inhibited good financial forecasting. It was particularly important that the Project Office avoid delay in elevating financial issues to higher headquarters. Timely actions on financial forecasting, combined with an improved Headquarters capability to maintain visibility on funding issues, helped eliminate unnecessary disruption of development. Also it was found to be important to minimize disruption in the flow of work and resources.

We have discussed lessons learned in management of engineering development and in business management. At a lower level of detailed management, program evaluation and control, other useful lessons can be learned. The work breakdown structure is fundamental to understanding and managing the technical development effort. After the work breakdown structure is established, a work assignment system must be provided to carry out the practical job of identifying and assigning day-to-day work packages. Next, a performance evaluation system must be put in place to evaluate progress that is made on these day-to-day work assignments. Finally, a cost/schedule control system must provide an overview of both progress and trends in the technical development effort within the planned constraints of schedule and cost.

In some phases of the Space Telescope program, the work assignment/performance evaluation/cost and schedule control functions were not performed well; schedule and cost suffered as a result. The Project Office team assigned to the Optical Telescope Assembly development had the primary task of assisting Perkin-Elmer in improving its performance measurement and automated scheduling systems. As a result of this combined Project Office-contractor effort, a great improvement in work planning and scheduling was accomplished.

g. Equipment, Facilities, Logistics

Actions were taken on several items that had been identified during the NASA review of Space Telescope as barriers to an effective and efficient development. Additional test and handling equipment needs were identified. Shortages of this equipment had been flagged by the review team as bottlenecks that had been delaying the progress of the highly complex and difficult development of the Optical Telescope Assembly and Fine Guidance Sensors. Also, additional industrial facilities, meeting the high cleanliness requirements of Space Telescope, were identified and authorized. The net effect of the addition to the program of test and handling equipment and facilities was to add flexibility by enabling parallel development of some of the more complex and difficult components.

In addition to these facility-related actions, a number of component spares were identified and added to the program. Shortages of spares had been identified by the review team as a cause of delay in development and testing, and as a potential cause of much more damaging delays in the future, during assembly and test of the integrated Space Telescope spacecraft.

The need for special test environments also might be viewed as a logistics requirement. Planning, and in some cases development, (for these items must be started early) and adequate resources must be provided to prevent program delays.

h. Technical Development

Although we do not discuss the technical development of HST at any length in this report, this aspect of the Space Telescope development provided some valuable lessons for program management.

One important lesson concerned the entire sequence of component and subsystem fabrication, integration and test. Actions were taken following the NASA review to insure that adequate intermediate testing would be provided. Delaying subsystems tests to maintain schedule adds risk to the systems tests downstream, and often causes excessive delays and greater risk. Second, additional spares were provided during assembly and testing in order to avoid delays as higher orders of system integration are achieved. Third, models, simulations and sensitivity analyses were added to verify design and to augment testing in evaluating development progress. Finally, special efforts were made to insure that associate contractors and subcontractors were involved early in the planning and execution of assembly and tests at the systems level. The goal of these efforts was to eliminate any confusion and inefficiency in coordinating the system level test activities of the associates.

A related lesson concerns the need for early planning for operational testing. Experience with the Space Telescope shows that some of the many associate contractors had difficulty in submitting test planning data on their particular subsystems. In part, this was a reflection of the more general problem of smoothing the perturbations in the flow of work for the smaller contractors. As the HST program advanced to the system level integration and test phase, increasing demands for data, test planning, test support and trouble shooting analysis were placed upon the instrument teams and other associates. The immediate demands of this phase made it difficult for the teams to prepare adequately for the longer range operational test requirements.

4. Contractor Management

Management of contractor efforts on a large science program such as the Space Telescope requires a good understanding of the companies involved. The technical strengths and weaknesses of the companies must be understood and considered in assessing various aspects of program risk. For example, a company may have a strong technical development capability, but be weaker in manufacturing and functional testing. The management style and organization of a company must be appreciated, too. For example, a company's application of matrix management in development and testing may make it difficult for the Government project management to influence directly the response of the company project office to real time problems. From this standpoint, understanding the corporate culture, and the corporation's relationships with previous Government customers in other agencies, can be very important.

Interactions among major contractors and their associate and subcontractors are very significant in a program such as the Space Telescope, in which there are many complex hardware, software, and management interfaces. Creation of a dedicated system engineering activity in the Project Office was intended, among other things, to coordinate the efforts of the associate contractors.

In managing contractors in large, cutting-edge programs, it is important to recognize the need for government involvement in project details at lower levels of project activity than would be necessary in less complex developments. NASA system program management recognized this need as a result of the NASA review of the space telescope, and instituted a number of actions, already discussed, to satisfy the need.

The various contracts for the project must provide a complete and coherent legal framework for coordinating and disciplining the complex interactions and interfaces among the contractors. Contracts must allow for the differences in size, experience and corporate culture among the contractors, and they must allow for an appropriate level of Government involvement and visibility into details of contractor activity.

The NASA Space Telescope review revealed a number of management shortcomings in contractor's organizations, as well as in Government organizations. Consistent with the spirit of NASA's management improvement actions, several contractors made adjustments in their management practices and organizations that helped improve the overall management of the Space Telescope program. Among these changes were some key personnel shifts. Perkin-Elmer appointed a new, highly experienced program manager and selected subordinate managers to oversee the development of major components. Lockheed Missiles and Space Company appointed a senior manager to head the newly established system engineering organization.

Contractors also made substantial changes in their project management organizations. At Perkin-Elmer, this involved forming two line management groups reporting to the project manager, one to manage the Optical Telescope Assembly and one to manage the Fine Guidance Sensor development.

These steps placed greater project line management emphasis on manufacturing, assembly and test, and provided better visibility of schedule and cost issues. Augmentation of the technical staff fleshed out these management structures and insured a strong effort on technical development, as well as on business management.

Several improvements in management practices, identified as necessary by the NASA review team, were put into effect by contractors. Work packages were defined more clearly, and mechanisms were established for authorizing and tracking their accomplishment. At Perkin-Elmer in particular, as we have described, special emphasis was placed upon improvement of the performance measurement system to provide better visibility on day to day performance of work against planned goals. A similar effort went into improving and automating their scheduling system. In addition, resource tracking systems and procedures were improved. This permitted a closer scrutiny of the correlation between resources expended and work accomplished. The presence in-plant of representatives of the Project Office provided a powerful catalyst for accomplishment of these needed improvements.

Another aspect of contractor engineering management that required special attention from the Project Office was the need to estimate special test equipment and special handling equipment requirements. Early in the program a lack of appreciation of the extremely high accuracy standards that grew out of the demanding HST performance requirements led to decisions that, in turn, caused some shortages of test and handling equipment.

A final challenge to the Project Office in improving HST program management was the need to develop the capability to evaluate and track contractor technical and cost baselines. An earlier lack of personnel resources in the Project Office and Headquarters had limited this capability, and it required vigorous Project Office action to overcome the deficiency.

E. KEY ISSUES FOR THE FUTURE

In this section, we condense the results of our analysis of HST program management and focus upon a small set of central issues that we judge to be important for the management of future large space science programs.

1. Headquarters Organization for Program Management

The Headquarters organization for program management should reflect the same total system perspective that is required at the Project Office level. The Headquarters should maintain a system development point of view at the top level, as opposed to a more traditional functional and administrative orientation. In particular, staff organization and procedures should provide for integration of several major program areas where such integration cuts across the traditional association of NASA Headquarters elements with individual NASA Centers.

The Headquarters Program Director should be provided with sufficient stature, visibility, and resources to permit him to manage forcefully and effectively. His organizational placement in the Headquarters must avoid, to the extent possible, any inherent conflict between a large flight system development and a continuing institutional commitment to a general level of science support.

2. Headquarters Involvement in and Oversight of Project Management

The Program Director must manage the program actively. The involvement of the Headquarters staff in project management must be broad, penetrating and sufficiently detailed to support the program Director's decision making process and to support the Agency-level coordination of resource planning.

3. Program Director's Decision Making Process

The Program Director needs two things to support him in formulating decision issues and making decisions on major program issues.

The Program Director needs a system for problem detection, analysis and issue formulation. In the Space Telescope program, this need was met by the Space Telescope Decision Support System, an automated system for providing management information and analyzing program issues. The degree of automation of such a system will be determined by the program requirements, but, in every case, the system should possess certain basic capabilities. First, a Program Office management information/decision support system should be a common user system. That is, it should provide information in a common format to users at all levels of the program. Second, the MIS/DSS should be a real time program, so that managers and decision makers at all levels can address current problems on the basis of current status information. Third, the MIS/DSS should be distributed broadly at all levels, not only so that a common base of information can be made available, but so that real time developments can be reflected by real time inputs at the level of origin.

The other thing that the Program Director needs to support the decision making process is a formal framework for formulating, reviewing and approving decision issues. In the Space Telescope program, this capability was provided by a Critical Decision Issue process, which was supported by formal organizational arrangements in Headquarters and in the Project Office.

4. Special Test Environments, Special Handling Equipment

As systems become more complex, so does the special test and handling equipment required to support development. The HST experience showed that special test environments can become major development projects in their own right, and that difficulties in developing test environments can impact on the critical path of the system that is to be tested.

In future programs this potential problem must be anticipated. Test capabilities requiring R & D should be identified and planned for. Allowance must be made in the system development schedule. The cost of developing test environments must be anticipated in program planning budgets. Finally, the system development contract should included these test environment developments explicitly.

5. Simulations and Models

Simulations and models are important to system program development in all phases, and must be supported adequately. They are important for verification of design concepts. They play a major role in testing, both in support of other test equipment and in augmenting testing. Simulations also have a major independent role in testing systems such as HST, for which some critical performance capabilities cannot be tested physically until the spacecraft is in orbit.

6. Spares

The operational phase of a program comes most readily to mind when discussing spares, but the HST experience showed that spares are critical to program success much earlier in development. Specifically, adequate spares must be available during component and subsystem integration and test, to avoid schedule and resource impact when failures occur.

7. Implementation of System Engineering and System Integration

The inculcation of an appropriate system management attitude in all elements of a system program is certainly a fundamental need, but we speak here of the more practical matter of actually implementing the chosen approach to system management. The HST experience showed that an early policy decision must be made by the Agency, specifying where and by whom the system engineering and system integration functions will be done. The cost of performing these functions, whether in house or by contract, must be recognized and budgeted from the outset. Failure to do this will only exact a heavy cost downstream. If the decision is that these functions will be done by a contractor, the initial contract must recognize the need, define the work, and budget the costs.

8. Management of Contractor Work

We make two points here, based upon experience with the Space Telescope. First, oversight of contractor work on a program of the size, complexity and cost of HST requires a higher degree of Project Office involvement in project details than has been required in the past. The implementation of a common user management information/decision support system helps solve this problem.

The second point concerns differences of "scale" among associate contractors on a large space science project. During the early development phases of a program, the associate contractors work on their particular subsystems, and are efficiently coupled with their tasking in terms of the size and pace of their work. However, as the system development advances to higher levels of integration and interaction, an increasing variety of demands are placed upon the associate contractors. These demands are for data, test planning, and test support. These demands tend to cause surges in workload with which the smaller associate contractors are not equipped to deal efficiently because of their small size and small business bases.

9. User Involvement

User contributions to program development are important in all program phases. Early in the program, user inputs are a key element in defining performance specifications. However, once the top level science mission performance specifications have been established, the involvement of users in development phases must be tailored to the needs of system program management. In the quite likely event that science users are also science subsystem developers, care must be taken not to put them in a position where their interests are in conflict. Clearly, this involvement must be adapted to the situation, keeping in mind the priority of system management considerations during development and integration.

10. Assessment of Technical Difficulty

A fundamental cause of many of the early problems in the Space Telescope program was a lack of understanding of the difficulty of achieving the desired science mission performance and the technical complexity of the development program. Unexpected technical development problems caused schedule delays. These caused resource problems. These brought about management decisions to restrain resources, which caused further development problems, and so forth. The key to breaking this chain was to establish adequate technical baselines, based upon a thorough understanding of the technical problem.

NATIONAL RESEARCH COUNCIL
COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES
2101 Constitution Avenue Washington, D.C. 20418-0001

BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE
(202) 334-3511

March 17, 1986

Dr. Burton I. Edelson
Associate Administrator
Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, DC 20546

Dear Dr. Edelson:

At your invitation, the NRC Panel on Global Habitability Assessment was established in September 1984. Its charge was to review the NASA initiative proposed under the rubric of "Global Habitability," with special attention to the

> "Concept, scope, goals, objectives, preliminary program definition, relationship with other domestic and international programs, and immediate steps that NASA may wish to consider."

During the course of three meetings the Panel reviewed the seminal document, "Global Change: Impacts on Habitability, A Scientific Basis for Assessment" (App. I - 1), the subsequent series of NASA Technical Memoranda, and several reports prepared under the auspices of the National Research Council (Appendix I). We were briefed by your staff and received a hundred page manuscript, "Earth Science Research Program: Global Habitability." We have followed with interest the several reports relevant to scientific rationale, implementation strategy, agency responsibility and coordination, and proposed levels of funding that have appeared either in final or in draft form during recent months (App. I - 17-20).

The concept and preliminary program definition as first set forth (App. I - 1,2), concluded that:

- o On time scales of decades, the ocean, atmosphere and biosphere function as an integrated system;
- o Biogeochemical cycles and the global hydrological cycle constitute the essential linkage within this system;
- o Observations from space would be a necessary element in providing integration on a global scale;
- o Planet Earth has entered a unique era when one species, the human race, has achieved the ability to alter its environment on a global scale;
- o A commitment by the United States government is essential to acquire the body of knowledge required to understand, to forecast quantitatively and to cope successfully with evolving global environment change; and that
- o There is an obvious need for international cooperation.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

The intrinsic scientific merit of this concept was underscored by two independent statements. The first was the challenge presented by G.D. Garland (Past President of the International Union of Geodesy and Geophysics) to the world scientific community at the 1982 General Assembly of the International Council of Scientific Unions to "address the remaining mysteries of the processes affecting Planet Earth and the region around it by illuminating the interaction between the physical and biological processes" (App. I - 3). The second was the proposal by H. Friedman at the Annual Meeting at the National Academy of Sciences in 1983 for a "bold, holistic venture" in global, interdisciplinary research to understand changes in the terrestrial environment and its living systems (see App. I - 4).

The National Research Council has recently released a report outlining a focused, international geosphere-biosphere program addressed to illuminating the interactive physical, chemical, and biological processes regulating the global environment, and has proposed some initial priorities (App. I - 10). The Advisory Council of NASA has established an Earth System Sciences Committee to (1) review the science of the Earth as a system, (2) recommend an implementation strategy, and (3) define NASA's role. This in-depth study, to be reported also to the Administrator of NOAA, is to be completed in 1986 (App. I - 18). In response to the President's National Space Strategy Directive, OSTP has prepared a document to insure effective action by and coordination among Federal agencies (App. I - 17).

Currently, an international study is underway under the auspices of the International Council of Scientific Unions to explore the feasibility of a cooperative, interdisciplinary, international program to illuminate the complex and synergistic physical, chemical and biological processes in the Sun-Earth system that determine its changes (App. I - 11,20). The ICSU study includes broader aspects of solar-terrestrial research and geology than in the recent NRC report and in the documentation on global habitability.

From an examination of the series of reports that have elaborated the concept set forth by NASA, it is clear that it is widely endorsed and a national and international programmatic framework is rapidly evolving. It is within this context that our Panel responds to its charge. We shall not review in detail the several hundred projects related to the proposed program in global habitability and supported in the Office of Space Science and Applications by a budget of the order of $200 million in FY 85. The scientific rationale and societal implications have been set forth persuasively in the documents cited.

We are convinced that the concept has both intrinsic scientific merit and can well lead to substantial societal benefit. We commend

NASA's initiative and urge NASA to pursue its efforts vigorously as a vital element in the emerging national and international activity. We have identified several scientific issues as background to our conclusions and recommendations.

Scientific issues include:

1. Multidisciplinarity. The program will involve intimate interaction among a wide-range of disciplines, including oceanography, atmospheric sciences, geology, geochemistry, geophysics, glaciology, hydrology, soil science, ecology, biology, solar-terrestrial physics and chemistry, and biochemistry. This characteristic creates an opportunity to build upon the achievements of the past several decades and accelerate the movement toward treating Earth as an integrated system. In some cases it will require reexamination of the (1) traditional emphasis in the scientific community on scholarly contributions to a specific discipline, as well as (2) the organization of some large research universities, and (3) the mission orientation of governmental organizations.

2. Diversity of Scales. The issue here is to develop new methodologies of analysis to relate small-scale spatial and temporal heterogeneity in terrestrial, fresh water, and marine environments to the much larger scale of physical phenomena in the atmosphere and oceans.

3. Remote Sensing. The challenge here is to establish an Earth observing system consisting of a scientifically driven array of remote sensing instruments coupled with surface and subsurface measurements, necessary in their own right and required for calibration and validation of space-based observations. For example, the need for global measurements of precipitation and evaporation is urgent and remote-sensing appears to offer an attractive possibility. Of particular relevance to NASA's role in the program are development of microwave multi-frequency radiometers on polar-orbiting satellites, complementing similar sensors on geostationary satellites, that hold promise of dramatically extending our knowledge of the global hydrological cycle. Similarly, the new capabilities envisioned for observations from space in the 1990s, should provide useful global information for both geology and biology and would help to fulfill the objectives of the proposed Global Tropospheric Chemistry Program and the Global Ocean Flux Study. High priority should be accorded to the development of sensors to measure gases and particles in the lower atmosphere. The success of remote sensing in the study of upper atmospheric chemistry offers some assurance that this issue

can be effectively addressed. The experiment with a sensor on the Space Shuttle to measure CO from space is an example of the kind of action that is desirable. The Space Station Complex, if implemented, could turn out to be an important vehicle for carrying remote-sensing instruments in the mid-1990s.

4. Continuity and Comparability of Observations. To be meaningful in detecting global change and discriminating between natural and anthropogenic change, consistent, comparable, long-term observations at a high level of accuracy are an imperative. Time series covering at least twenty years are needed. This could cover two solar sun-spot cycles, the eruptions of a number of volcanoes and the occurrence of several El Ninos, as well as an interval that would permit assessment of the major effects of deforestation. Since an international program is clearly necessary, sensor intercalibration of the several national satellites involved will be required. Attention will have to be given to techniques for simultaneously assessing physical, chemical and biological processes. The analysis of paleoclimatic data offers attractive possibilities to extend shorter time series.

5. Data Management, and Data Access. The present capacity to collect data descriptive of the Earth exceeds the capacity of the world scientific community to assimilate those data. The prospect of "parallel processing" with speeds orders of magnitude greater than today's supercomputers suggests that the technology for handling this flood of information will soon be available. Much more than advanced technology will be required, however, to establish adequate, long-term global data bases that will be readily accessible to the research community. A report of the Space Science Board of the National Academy of Sciences has investigated these issues in considerable depth (App. I - 12). We concur with their findings and recommendations. The NASA Pilot Ocean Data System and the NASA Pilot Climate Data System are initial attempts to construct practical solutions to very real data management and information system problems.

6. Global Scientific Models. Quantitative models will be required that link the atmosphere, oceans, cryosphere, marine and terrestrial biota, with sufficient capability to explain paleoclimatic changes and to project the long-term (decades to centuries) evolution of the Earth system. The complexity of these models will require access to supercomputers.

7. Disciplinary Scope of the Program. There has been a lively discussion during the past year of the degree to which solar-terrestrial physics and chemistry and solid Earth sciences should be involved. This issue is addressed in our conclusions and recommendations.

Among institutional issues we recognize are:

1. Interagency Coordination and Assignment of Responsibility. The task requires active participation of a number of governmental agencies. In particular, responsibility should be assigned to a specific agency for collecting and archiving the space and ground-based measurements over periods of decades. This issue has been examined in detail by the Office of Science and Technology Policy (OSTP) (App. I - 17) and we concur with their findings.

2. Role of the National Scientific Community. An adequate scientific infrastructure is essential to the successful implementation of the proposed program. NASA's invitation of proposals for interdisciplinary research, with provision for peer review, is an exemplary model. Provision for sustained funding for individual scientists and groups of scientists will be important for the effective utilization of the vast quantities of data archived at considerable expense. Two recommendations of the OSTP report (App. I - 17) are relevant to the role of the scientific community: (1) that the NSF, NASA and NOAA (a) support basic research in all fields of Earth Sciences on a competitive basis, (b) support training of scientific personnel, (c) enhance its support of research on global ecosystem dynamics, and (d) provide advanced scientific computing for the utilization of space-derived Earth Science data, and (2) that the National Academy of Sciences be requested to provide a continuing evaluation of progress in the field and advice on the program through a committee representative of the NRC boards and committees concerned with relevant programs currently underway. We wish to emphasize the point made in the OSTP report concerning the urgent need to augment support of biological research addressed to problems of global ecosystem dynamics. This will require special attention to training system ecologists.

3. The International Institutional Framework. This has been touched upon only lightly in the published and draft documents. Clearly, one of the reasons that the proposal for an international program in Global Habitability at the UNISPACE Conference in 1982 did not generate an enthusiastic response was because of the perception internationally and domestically that NASA was aggressively

seeking a special role of dominance. The experience of the past two decades in geophysical studies, in world climate research, and in global carbon-balance studies has demonstrated the great importance of international collaboration in these world-scale questions. The needed scientific oversight has been provided by ICSU, and its various adhering bodies, which have played unique international coordinating roles, beginning with the IGY. ICSU is presently considering a new global research program, the "International Geosphere-Biosphere Program: A Study of Global Change" (App. I - 20), which contains many of the proposed NASA objectives. It goes well beyond traditional disciplinary research. Working Groups have been established dealing with:

- Terrestrial Ecosystems and Atmospheric Interactions;
- Marine Ecosystems and Atmospheric Interactions;
- Geological Processes, Past and Present;
- Role of Solar Emissions in the Upper Atmosphere and in Relation to the Earth; and
- Remote sensing.

National committees are being established in several countries. A mechanism by which national governments will act in concert may have to be invented, given the highly interdisciplinary nature of this program and the mission orientation or perceived inadequecies of some UN specialized agencies. Coordination with other space agencies is, of course, a vital need. Of particular importance is the international collaborative effort required to design an international data archiving and information system.

4. Relation Between Ongoing and Planned Earth Science Programs Involving Space Technology. This topic is being treated by the Earth System Sciences Committee (ESSC) of the NASA Advisory Council. Given foreseeable financial constraints, the task of assigning priorities to these projects will loom as a formidable but important undertaking. Many international programs now underway are of fundamental importance to the NASA proposal. The degree of relevance of these activities varies widely. In addition, the intellectual span of this assemblage of programs is large; each program has its own pace; each is at a different stage in its development; and each could be perceived as presenting potential conflicts with other programs and with any new proposals. Since a comprehensive examination of earth processes is emerging, these programs actually complement each other. For example, the World Climate Research Program, and associated World Ocean Circulation

Experiment and Tropical Ocean and Global Atmosphere Project, will provide an essential database and understanding of many physical processes. They are an integral part of a comprehensive study of physical, chemical, and biological processes that is required to view the Earth as an integrated system. Long-term support should be continued. It may be necessary to consider an appropriate linkage at the international level between this multidisciplinary program and ongoing or planned programs. The analysis of ESSC, since it includes many of the observational components, will help to give a strategic basis for considering this linkage.

5. The Internal Program Structure within NASA. Even as NASA continues to support and stimulate both a domestic and an international discourse, it would be in order for NASA to ensure coherence among the several programs currently under way at Headquarters and within NASA centers that bear directly on the initiative under consideration. Effective communication is the key to establishing interdisciplinary programs, and NASA should take whatever steps are required in order to ensure such communication.

With respect to the Panel's conclusions from this study, the following points are germane to our charge:

1. The concept of "Global Habitability" has substantial intrinsic scientific merit and has stimulated a wide-ranging discussion nationally and internationally within the scientific community and among national space agencies. What started out as a bold idea is now assuming meaningful form and substance.

2. With respect to scope, we conclude that solar-terrestrial physics and chemistry and solid Earth Sciences should be involved in the proposed multidisciplinary program to the extent that there is significant interaction between these domains and the rest of the biosphere on time scales of primary interest to this program. Thus, the energy flux of solar radiation arriving at the Earth, particularly variations in the solar visible and ultra-violet spectrum, are integral elements of "Global Habitability," as are the roles of the solid Earth in the biogeochemical cycling of nutrients and water and the changing quality of biologically productive soil and of ground water. Some NASA programs such as those on Crustal Dynamics and the proposed International Solar-Terrestrial Physics Program should proceed on their own merits and constitute autonomous efforts within the Office of Space Science and Applications bearing in mind their potentially important

relevance to the proposed multidisciplinary program. It would be appropriate to incorporate proposed projects in Global Tropospheric Chemistry and Global Ocean Flux Study directly as integral parts of the NASA program since they address directly crucial chemical and biological processes. Plans for the Global Tropospheric Chemistry Program are now well advanced and the NASA contribution should proceed without delay.

3. We conclude that the goals of the NASA proposal have matured and now, in effect, are embraced within the draft statement of the ICSU ad hoc Planning Group for the International Geosphere-Biosphere Programme: A Study of Global Change (App. I - 20):

   "To describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment it provides for life, the changes that are occurring in that system and the manner in which they are influenced by human actions."

4. From this statement of an overall goal, the specific objectives of the NASA endeavor will require activity in six areas:

   - Studies of the interactive physical, chemical and biological processes that govern global change;
   - The development of a new generation of coupled models of the environment;
   - The design of suitable tests to guide the development of these models and the understanding of the processes involved;
   - Programs of observation tailored to provide the data needed for these activities;
   - A collaborative international effort to develop a global remote sensing system for observing carefully selected parameters for detecting global change, including a Space Station Complex, if that is implemented; and
   - The development of a "user friendly" global information system which will provide ready access to observational data for research scientists.

   Pursuit of these scientific objectives will, as pointed out in the seminal document (App. I - 1), constitute a major advance in providing some of the scientific information necessary for actions to ensure that the carrying capacity of Planet Earth will be preserved and enhanced to accommodate its rapidly growing population -- particularly in the Third World.

5. It appears to us that the preliminary program definition of the global habitability proposal has now been elaborated and given focus by the NRC reports (App. I - 4,8,9,10) and by the studies of the Earth System Sciences Committee (ESSC) of the NASA Advisory Council. ESSC has set forth a near-term program (1986-1996) consisting of (a) specialized space missions, (b) other observing opportunities, (c) basic research, (d) the information system, and (e) instrument development. This is to be followed by a more general program definition beginning in the mid-1990s which addresses the potential of Polar-Orbiting Platforms, Geostationary Platforms and an Earth Observing System. We commend this updated outline of activities to NASA as an appropriate program structure.

6. Immediate steps are embraced in the recommendations which follow.

In summary, we recommend that:

1. **NASA make a formal commitment to the type of program it proposed in 1982 and do so within a framework that consolidates its array of activities included in the term Earth System Sciences. The NASA effort will be a key element of the U.S. contribution to the emerging ICSU program identified as "IGBP: A Study of Global Change." However, given the compelling scientific merit of the NASA program, it should proceed immediately in cooperation with NOAA, NSF and other governmental agencies even as the international program is being formulated.**

2. **NASA examine its organizational structure with special attention to closer integration of biology and the physical sciences and balance among remote-sensing, in situ observations, modeling, and information systems.** The most **successful research programs of NASA have been those identified with a specific primary mission for which research managers have been held directly accountable. The interdisciplinary research needs of this program cut across the primary managerial lines at NASA and suggest a particularly designed management structure.**

3. **To ensure a scientifically driven program, NASA and the other agencies involved may wish to build upon the close relationship between the federal government and the NAS/NRC. Because of the intrinsically global character of the program, and the imperative of participation by many countries, NASA and the other agencies should give special attention to relating its activities to those at the international level. Four areas are critical:**

- Scientific planning; the linkage is in place through NAS/NRC and ICSU;
- Implementation by national governments and multinational agencies such as the European Space Agency; traditionally, this is coordinated through U.N. specialized agencies, but other patterns exist and should be explored;
- International collaboration in remote sensing and information systems; bilateral agreements or coordination through ICSU's COSPAR, CODATA, and the World Data System are recommended; and
- Oversight and evaluation; international institutional innovation will likely be required to link the scientific community and national governments.

4. We concur in the recommendation of the OSTP Report (App. I - 17) that the National Academy of Sciences play a continuing role through a standing committee to provide advice and recommendations to the interagency group responsible for governmental oversight of this undertaking. With respect to program planning at the international level, we encourage NASA to interact with the International Council of Scientific Unions through the National Research Council.

5. NASA make a special effort to bring together and strengthen its program in ecological and ecosystem research. Effective communication is the key to establishing multidisciplinary programs, and NASA should take whatever steps are required to ensure such communication.

6. Incorporation of the emerging program in Global Tropospheric Chemistry and Global Ocean Flux (App. I - 14,15) into the new multidisciplinary program should be explored.

In bringing to a close our assessment of the "Global Habitability" concept we wish to express our appreciation for the opportunity provided to us to examine a proposal that has stimulated a great deal of thought in the United States and other countries. We are persuaded that the steps now underway, nationally and internationally, to develop a global collaborative effort that will embody -- and perhaps extend -- the principles originally set forth by NASA in 1982 will be successful. We have been particularly encouraged by the personal interest that you, Shelby Tilford and

Robert Watson have taken in our work and we wish you and NASA the success we are confident you will achieve in weaving the unique contribution of your organization into the most complex program yet to be envisioned by the world scientific community and to be implemented by national governments acting in concert.

With every good wish,

Sincerely yours,

Thomas F Malone

Thomas F. Malone, Chairman
Panel on Global Habitability Assessment

Members of the Panel on Global Habitability Assessment:
Thomas F. Malone, Chairman
Ralph J. Cicerone
John A. Eddy
Marvin R. Holter
Carl Kisslinger
Orie L. Loucks
Frederic C. E. Oder
Roger Revelle
Karl K. Turekian

ROYALTY RECOVERY FOR LAUNCH SERVICES STUDY

NASA Headquarters

Office of Commercial Programs

October 14, 1986

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I. Introduction and Background

The purpose of this study is to report on the feasibility of providing Shuttle launch services on the basis of royalty recovery over the economic life of commercial products produced or processed in space. This study was initiated per direction contained in Section 112 of Public Law 99-170, the NASA Authorization Act of 1986. Subjects addressed in this study include types of royalty recovery and deferred payment plans, examples of such plans in the Federal Government, and current legal constraints.

In 1985, the NASA Office of Commercial Programs (OCP) developed a new type of agreement for working with the private sector. This instrument, called a Space System Development Agreement (SSDA), allows deferred payment for Shuttle transportation and other related NASA services. Congress asked NASA, in this study, to determine the feasibility of establishing a flexible payment policy that, in effect, expands the existing "fly-now, pay-later" feature of the SSDA to a broader range of commercial customers flying fully reimbursable payloads. As a quid pro quo for this increased financial liability, Congress also asked NASA to examine the use of a royalty payment structure which would allow the agency to collect revenues over and above costs actually incurred by NASA.

Contributors to the study were NASA's Office of Commercial Programs (OCP), Office of the Comptroller, Office of General Counsel, and the Office of Space Flight.

II. Current Reimbursement Structure

This study addresses payment for services provided to non-U.S. Government payloads launched on the Shuttle. For purposes of this study, these payloads are classified as either fully reimbursable payloads, which fly as primary payloads, or commercial development payloads (such as materials processing experiments), which fly predominantly as secondary payloads in the Shuttle middeck or on carriers in the cargo bay.

Fully Reimbursable Payloads

NASA's statutory authority to negotiate and sign agreements and other cooperative arrangements stems from its original enabling legislation, the 1958 National Aeronautics and Space Act (Public Law 85-568, 42 U.S.C. § 2451 et seq., 1970, enacted by the U.S. Congress on July 29, 1958).

NASA launches domestic and foreign payloads on a reimbursable basis in accordance with published Space Transportation System (STS) pricing policy. Reimbursement for Shuttle services is governed by 14 CFR 1214.1 which specifies reimbursement in full prior to launch.

The basic agreement as to what is to be launched, on what flight, and how many scheduled launches are anticipated is set forth in the Launch Services Agreement (LSA), which is a contract between NASA and the customer which establishes exact costs and advance payment schedule. Under this agreement, any knowledge gained by the corporation during space activities may be kept proprietary and any and all benefits of space activities accrue to the company.

Customers who seek to obtain manifesting for fully reimbursable payloads on the Shuttle must complete an "STS Form 100" and remit an initial payment of $100,000 per payload. Payments begin approximately 3 years in advance of the launch and are scheduled at precise intervals. Total payment is predetermined by the established pricing policy for the time period in which the launch is to take place.

Commercial Development Payloads

Commercial development payloads are characterized by the promise of benefit to the long-term U.S. economic/commercial development of space. They are generally "secondary" payloads which are flown on a "space-available" basis in the Shuttle cargo bay or middeck after the requirements of the primary payloads, the flight and the crew have been met.

Commercial development payloads are flown under a variety of arrangements designed to reduce financial and technical risks of conducting commercial activities in space. Joint Endeavor Agreements (JEA) and SSDA's are the basic agreements under which commercial development payloads are flown.

JEA's. The JEA is a cooperative arrangement in which a U.S. domestic corporation and NASA mutually agree to pursue common program objectives and share responsibility and financial risk in a commercially-oriented, space-related R&D activity. A JEA is a legal arrangement between NASA and an industrial partner in which the commercial firm proposes an experimental program or a technology demonstration, conducts the necessary ground-based investigations, and develops the required experimental flight hardware. As incentive for this investment, NASA provides technical support, Shuttle flights, hardware integration, and data collection at no cost. As further incentive, the private entity, under most circumstances, retains patent and data rights and proprietary rights to the experimental results. NASA requires that the private participant make a good faith effort to apply commercially any promising technologies on a timely basis.

To be flown under a JEA, the project must be a pure research and development effort with commercial potential, but have no immediate commercial product or service market. During the course of the JEA, no revenue can be derived by the commercial entity as a result of activities conducted or materials produced under the JEA. The partner may be obligated to share information gathered from the project with NASA. The agency will, in turn, use this information to expand commercial development of space.

SSDA's. As discussed earlier, an SSDA (formerly known as a Modified Launch Services Agreement) is an alternative contractual arrangement that has been offered to developers of space hardware projects. It is used to support the first flight(s) of a new industry which has the potential for providing significant national economic or social benefit and where the revenue will be generated directly because of the flight(s). The SSDA permits a company to defer launch services payment until some time after the launch. Deferred payment provisions may take on a number of variations and are tailored to the circumstances of a particular private enterprise. There must be a reasonable expectation of launch charge recovery in accordance with the agreed-upon terms and the company must provide a business plan which is acceptable to NASA.

On March 7, 1986, the NASA Policy Review Committee approved a pricing policy for JEA's and SSDA's. This pricing policy can be summarized as follows. There will be no charge to JEA customers for provision of standard and nonstandard services. Standard services are those services provided by NASA to all users for transportation of their payloads into low Earth orbit. An example of a standard service is the transportation of a payload on the Shuttle from Kennedy Space Center into a 160 nautical mile, 28.5 degree inclination circular orbit. Nonstandard services are those services that, in addition to standard services, are required for flight of a payload. An example of a nonstandard service is the use of NASA-developed attachment hardware.

If JEA customers require optional services, they must be negotiated on a case-by-case basis. Optional services are other services (that are neither standard nor nonstandard) that are specifically requested by the customer and that can reasonably be provided by NASA upon request. An example of an optional service is extra vehicular activity by the flight crew. The customer will arrange for the provision and reimbursement of optional services through a separate agreement with the furnishing NASA Field Center. The price of optional services will be based on a fixed price or on an additive cost basis and customers will be furnished an estimate of the charges before any services are performed. Where the fixed price of an optional service has been previously established, the customer will be charged that price. If a price has not been established, the customer will receive an auditable accounting of the actual cost of the service.

Under an SSDA, the agency may vary the amount of reimbursement for standard and nonstandard services as well as provide for deferred payment of all charges. The charges assessed for services may vary depending on the circumstances of a particular commercial endeavor. Customers will pay a variable charge for standard and nonstandard services, up to full price recovery at NASA's discretion. For example, for research flights conducted under an SSDA, there may be no charge for standard services. For fully developed commercial activities, NASA may charge full price for both standard and nonstandard services. The deferred payment schedule, which will apply to all services provided to the customer, will be established on a case-by-case basis according to the circumstances involved.

In all SSDA's, full price will be charged for optional services, and the customer will be furnished a cost estimate prior to any work being performed. Once the service is completed, the customer shall be given an auditable accounting of the costs on which those charges are based, except when a price has been previously established and approved by the NASA Comptroller.

III. Federal Government Cost Recovery

Cost income recovery for the Federal Government may take one or more of many forms, among which are royalty fees, recoupment, and reimbursement.

Royalty Recovery

In its broadest sense, a royalty is a share of profit reserved by an owner for permitting another the use of property. The property usually comprises natural resources, or intellectual property rights, such as patents, copyrights, or trade secrets. For example, in the case of the Federal Government a royalty may be derived from the leasing of oil- and gas-bearing lands to commercial producers, or from the licensing of government-owned patents for commercial development.

For the purposes of this paper, it is assumed that the nature of the royalty charge will be determined by market forces. The royalty fee constitutes some percentage of either net or gross profit, derived from the specific asset during its operational life span. In no way does this use of the term "royalty" imply any transfer of ownership rights to the recipient of the royalty payment.

Various legal constraints affecting NASA's ability to utilize royalty charges as a profit generating versus pay-back method will be addressed subsequently in this paper.

Recoupment

Recoupment is a special kind of cost recovery where nonrecurring costs (such as R&D costs) are recovered from the recipient of a special benefit (above those accruing to the public at large) conferred by the government. The recipient is usually a contractor or subcontractor where government funding enhances a commercial product line.

Thus, the term "recoupment" is not synonymous with "royalty" in common usage in that its purpose is to obtain pay-back of certain nonrecurring costs rather than to obtain a share of profits derived from the lease or licensing of property rights.

The Federal Government policy on recoupments is based on the Council of International Economic Policy, Decision Memorandum No. 23, and implemented by NASA in NMI 5109.13A. A particular aspect of recoupment is that it is not related to any patent rights conferred on the recipient under present government patent policies.

Reimbursement

Reimbursement is a charge for the performance of services or for access to or use by others of facilities or equipment owned or controlled by the Federal Government. Shuttle launch services are currently offered on a reimbursable basis to commercial customers. Prices for these services were established on the basis of operations cost recovery and no attempt was made to recover the sunk R&D costs of the Shuttle.

Appendix 1 contains detailed examples of royalty and recoupment mechanisms in use within the Federal Government.

IV. Legal Constraints

The question has been raised as to whether NASA presently has, or should have, the legal authority to charge its customers for launch and in-orbit services by receiving an open-ended royalty that could exceed normal payment levels, rather than charging a fee which is related to the full costs or a portion of the costs incurred by NASA in performing such services. For purposes of this discussion, a royalty is defined as a percentage of the revenue or profit accrued by the customer from commercial transactions which were derived from the benefits of the services rendered to the customer by NASA.

The standard procedure for a government agency receiving funds from a nonappropriated source is to promptly deposit all such money into the Miscellaneous Receipts of the U.S. Treasury (31 U.S.C. 3302(b)). There are several exceptions to this rule. One is used by NASA in order to replace its appropriations through revenues collected from launch services customers. In order to furnish launch services to customers, NASA expends appropriated funds. NASA then charges the customer for such costs and deposits such revenues into a special Treasury account. The money from this account is transferred back to NASA to replace all or a portion of the appropriated funds which were spent in order to perform such launch services. This method of replacement of appropriated funds has been recognized by the GAO in 55 Comp. Gen. 1293, 5 Comp. Gen. 734, and 6 Comp. Gen. 337.

Using this authority mandates that the funds acquired from the nonappropriated source must be a repayment for expenses borne by the agency in performing the services in which appropriated funds were used. Without specific statutory authority granted to an agency, any fees collected which are not directly related to the expended costs cannot be held by the agency but must be deposited into the Treasury because such funds would be deemed to be an augmentation of appropriations.

The federal courts have generated the legal requirement that fees charged by an agency should be relevant and limited to the cost of government services rendered.

Royalties, as defined herein, are open-ended and bear no relationship to the cost to the government but are based upon a percentage of the revenues or profits to the customer. Such fees might be a fraction of the government's costs, or they might eventually amount to a figure many times the actual cost.

Such a fee, unless capped by the actual costs to the government for its services or authorized by statute, would not constitute a fee for services rendered but deemed by the Supreme Court of the United States as a federal tax based upon profits or earnings.

This uncapped revenue stream would be illegal (National Cable Television Association v. U.S., 415 U.S.. 336 (1974)). In citing this case, the U.S. Court of Appeals, D.C. Cir. in National Association of Broadcasters v. F.C.C., 415 U.S. 336, 1129, footnote 28 (1976), stated:

> "Once agency charges exceed their reasonable attributable cost they cease being fees and become taxes levied not by Congress, but by an agency. This, the cases hold, is prohibited."

Unless special and explicit congressional statutory authority is given (in 31 USC 3302B) to NASA, the agency would not be able to acquire royalties in lieu of seeking reimbursement for a portion of the cost spent.

There would appear to be no restriction with respect to using a flexible arrangement structured and triggered like a royalty for the purposes of reimbursement to collect a sum of money that is in some manner equal to real dollar costs incurred by the agency for actual services plus debt financing costs to the U.S. Treasury. This is being done currently with respect to commercial development payloads in SSDA's.

V. Current NASA Use of Deferred Payment Plans

NASA has signed two agreements thus far containing deferred payment provisions for Space Shuttle launch services. NASA signed the first in August 1985 with Space Industries, Incorporated, (SII) of Houston, TX. The other was signed in November 1985 with the Geostar Corporation.

The "fly-now, pay-later" concept is the primary leverage feature in each of these agreements. Until the SSDA was developed, all reimbursable payloads were required to sign an LSA and pay for services prior to launch. NASA developed this concept because the commercial space policy precludes the provision of free Shuttle flights to fully developed, commercial systems that can immediately generate revenues. In each of these two ventures, NASA concluded the potential economic and other benefits to the Nation were so significant that some form of NASA assistance was warranted to ensure the venture would be undertaken.

a. SII Agreement. Under this agreement, SII will design and develop a permanently orbiting industrial facility for the primary purposes of processing commercial low volume, high value fluids and crystals in space. The facility will be manned only during periodic servicing while attached to the Shuttle or subsequently to the Space Station. NASA will launch two facility modules and one resupply module on three Shuttle flights over a 5-year period. SII will then pay NASA 12 percent of its yearly gross revenues, beginning 24 months after the first launch, until its launch costs, to include adjustment for inflation, are fully reimbursed.

b. Geostar Corporation Agreement. Under its agreement with the Geostar Corporation, NASA will launch the first three of six fully operational Geostar satellites on a deferred payment basis. The six satellite Geostar system will provide global position determination with high accuracy in friendly readout terms, unique identification of party, and nonvoice message transfer services according to technology developed by Geostar which the FCC has adopted as the baseline technology for the new radiodetermination satellite system industry. Potential commercial uses of the Geostar system include fleet management, aircraft collision avoidance, search and rescue, law enforcement, and a number of other possible commercial uses. Geostar will reimburse NASA for each launch over a 5-year period according to a fixed payment schedule. Reimbursement will include adjustment for the cost of money to the U.S. Treasury. NASA will also launch a partial demonstration package according to the same financial terms. Under the agreement, NASA is given first right of refusal to launch the remaining three of six Geostar satellites.

Since the total payments are fixed (except for escalation) and limited to NASA's costs, the deferred payment plans of NASA's current SSDA's are deferred reimbursement plans rather than true royalty recovery.

Appendix 2 contains a detailed discussion of deferred payment concepts.

VI. Expansion of Deferred Payment Plans

The SSDA concept was developed to facilitate the commercial development of space by the U.S. private sector in cases where a JEA is not appropriate or, subsequent to the R&D phase typically covered by the JEA, where continued NASA assistance is required and merited. The deferred payment concept could also be made available to customers flying fully reimbursable payloads.

There are clearly advantages and disadvantages to both the customer and the Federal Government to the expansion of "fly now, pay later" to a broader range of customers. From the U.S. Government standpoint, there is the potential that start-up of high risk ventures may eventually provide tax revenues. However, such expansion also introduces the U.S. Government into a new phase of the capital supply market, in competition with commercial suppliers. From the customer's standpoint, deferred payments relieve the cash flow squeeze in the early stages of the venture and allow lower capitalization for new ventures. However, if applied to existing industries it will give an advantage to new customers entering the market over customers whose payloads were previously launched on the Shuttle.

Appendix 3 contains an analysis of the relative impact on the Federal Government of two deferred payment options for Shuttle launches.

VII. Summary/Conclusions

This study considers the feasibility of providing Shuttle launch services on the basis of royalty recovery over the economic life of commercial products produced or processed in space. The study addresses the issue of expanding the deferred payment feature of SSDA's to a broader range of customers and the use of a royalty payment structure which could lead to the agency collecting revenues over and above costs actually incurred by NASA.

In examining variations of royalty recovery, as required by Congress, the agency is faced with legal constraints on revenue collection. NASA may collect only up to its cost for providing services. Should Congress decide that supplementary appropriations through royalty recovery are desirable for the agency, specific statutory authority is required.

APPENDIX 1

Examples of Current Government Recovery Systems Based on Sales Revenue from Commercial Transactions

Two major examples where payments by commercial firms to the U.S. Government flow from sales activities derived from the use of federally-owned resources are royalty fees paid for the use of government "property," and the recoupment of funding for contracted projects which result in near-term enhancements to commercial products.

a. Royalty Fees

(1) Lease of Outer Continental Shelf (OCS) Lands to Commercial Producers. In terms of revenue to the government, the most successful royalty system involves the leasing of OCS oil- and gas-bearing lands to commercial producers. Almost $4 billion was received in royalty fees from the sale of oil and gas produced on offshore federally-owned property administered by the Department of Interior (DOI) in 1984. The initial lease of these properties is secured through a competitive bidding process with the successful bidder chosen based on the greatest up-front "bonus" offered to the government. The lease holder is then required to pay a fixed royalty of usually 12-1/2 or 16-2/3 percent of the gross market value at the wellhead on all oil or gas produced. Thus, since the price of oil fluctuates with market conditions, the percentage of the royalty remains unchanged though the absolute dollar value of the royalty per unit of production may vary.

The minimum authorized fixed royalty charge is 12-1/2 percent of the market value of the product. This low royalty rate is intended to increase industry's incentive for bidding by compensating producers for any high-cost risk undertaken in developing oil and gas reserves. The 12-1/2 percent royalty is appropriate, for example, where exploration and operation costs are high due to deep-water drilling situations, extreme weather conditions, and other considerations. (In addition, to promote increased production on a lease through direct, secondary, or tertiary recovery means, the royalty may be reduced or eliminated).

In 1978, the OCS Lands Act Amendments (Public Law 95-372) expanded the authority of DOI to use different bidding schemes in lease sales rather than the traditional bonus bid, fixed 16-1/2 percent royalty system. Pursuant to the authority in the 1978 amendments, DOI has evaluated a number of possible systems, and several have been implemented on a trial basis for offshore lease sales. These have included taking a fixed share of the net profits, allowing bidders to propose a royalty percentage (with the cash bonus fixed), and using a sliding scale royalty formula in which payment is a function of prices and production levels. However, there has been no clear indication that any alternative system has significantly increased competition for leased acreage, and the traditional system is still used for essentially all tracts offered in current lease sales.

(2) Granting of Licenses for the Commercial Production or Use of Federally-Owned "Inventions." Another common example of royalty fees being paid to the government stems from the granting of licenses to private concerns for the commercial production or use of federally-owned "inventions." An invention or design, covered by a government-owned patent or patent application in the United States, or a patent application (or other form of protection) in a foreign country, title to which has been vested in the U.S. Government, may be made available for licensing when in the public interest. Several federal agencies (e.g., the Departments of Energy, Commerce, and Defense, as well as NASA) use the general licensing authority of the government (35 U.S.C. Sections 207 and 208) to promote public sector use of technology arising from federally-supported research and development (R&D) activities.

Under NASA's own regulatory procedures implementing 35 U.S.C. 207 and 208 (14 CFR Part 1245), which also reflect government-wide licensing practices, the agency may grant nonexclusive, partially exclusive, or exclusive licenses for inventions under its custody. The terms and conditions under which such licenses are established normally require the payment of a royalty fee by the licensee.

NASA requires a license holder to make an initial payment to the agency which offset some of the administrative costs incurred in granting the licence and obtaining the initial patent protection. In addition, a "running royalty" payment is required which is derived from the commercial sales of the invention. The amount of this royalty is negotiated at the time the license is granted and is based on a percentage of the "net sales invoice" price (i.e., sales less shipping costs, returned goods, retailer costs, etc.). It is not, however, related to the NASA expenditures used to develop the technology from which the invention is derived.

In general, when the royalty is negotiated, NASA seeks to establish a level of payment which is consistent with that charged under licensing arrangements in private industry for a similar category of inventions. It represents, in a very loose sense, a balancing of what the market will bear against incentives for private investment. Thus, for example, the royalty sought for licensing a "mechanical device" may range from three to five percent of net sales, which is the industrial standard for such agreements. More sophisticated inventions are negotiated to fit the circumstances. In so doing, a number of factors may influence the percentage which is actually agreed to. These include the estimated cost of any further private R&D needed to make the invention suitable for commercial applications, the projected cost and sales quantities of the item, and the level of risk involved in successfully adapting the invention for commercial use. For example, a requirement for a significant capital outlay by the licensee in order to adapt an invention for commercial purposes would argue against seeking a high royalty fee. In addition, NASA might agree to vary the amount of the royalty charged over the duration of the license agreement. In some cases, to incentivize the licensee to promote the spread of the technology through increased sales, NASA might agree to reduce the royalty fee once sales rose beyond a certain level. Also, if significant private outlays are needed to bring the invention to market, royalty payments may be delayed until some of such outlays are recovered.

The agency's licensing activities generate approximately $100,000 a year in royalty fees. As required by law (31 U.S.C. 3302 (b)), all royalty payments are deposited into the U.S. Treasury.

b. Recoupment. NASA has occasionally derived royalties from programs focused on near-term results to meet national needs. Very rarely have such programs resulted in the production of an end-product which could offer significant potential for commercial sales by the contractors involved. In such cases, NASA has required that the cost of the effort be shared by the industrial participants, and that a recovery-of-cost provision be included in the contract which allows the government to recoup its investment if the technology directly results in a new commercial product or product improvement. Two significant examples of NASA programs in this category are the performance improvement elements of the Refan and the Engine Component Improvement (ECI) programs, which stem from NASA aeronautics research endeavors.

(1) NASA Refan Program. The Refan program was initiated in 1972 to provide a retrofit option for FAA-mandated noise reduction on commercial aircraft. It was conducted under several NASA contracts with commercial aircraft and jet engine manufacturers. These contracts (which were either cost-sharing or no fee agreement) contained government cost-recovery clauses for technology used for the retrofit of existing aircraft or for the sales of new aircraft in which this technology was incorporated. The NASA investment in the program totalled $44.5 million.

As a result of this program, refanned aircraft noise levels were significantly reduced. However, due to the high initial cost of refit, FAA did not specifically require airlines to use the refanned option to meet stricter noise regulations. This technology, though, has been incorporated into some new aircraft. While the recoupment provisions are open-ended, full NASA cost recoupment is not expected because the technology is only being applied to new aircraft and engine production, and the applicability of the advanced technology is judged to be less than 100 percent. To date, approximately $7.5 million has been recovered.

(2) NASA ECI Program. Under the ECI program, efforts were made to develop jet engine components which would, through improved performance capability, reduce the fuel consumption of current model engines. Since the performance enhancements sought held promise of near-term energy efficiency improvements in commercial jet engines and aircraft, recoupment clauses were incorporated into several development contracts with major engine and aircraft producers. A recoupment provision required that 1 percent of gross receipts from sales of parts and engines derived entirely or substantially from ECI-funded R&D be paid to the Treasury, up to the $24.3 million NASA investment in the program. Approximately $6.4 million has been recovered to date.

APPENDIX 2

Deferred Payment Concepts

Deferred payment plans can be structured in terms of a royalty arrangement for recovery of launch price out of some measure of revenues or profits based on the project's ability to pay. They can also be structured in terms of a fixed payment schedule with a fixed period over which full reimbursement to NASA will be made. The relative merits and some of the more obvious variations of each such structure will be discussed in the next section. However, the essence of the concept is the deferred payment feature. Royalty arrangement versus fixed payment schedule structure, and variations thereof, is not at the core of the concept. That a business venture, projected to be profitable over the long term, can fail because of upfront cash flow problems [1] suggests that the deferred payment feature is the essence of the attractiveness of the concept to the private sector with structure being secondary.

Even private capital investment projects that are ultimately very successful experience relatively heavy negative upfront net cash flow positions and initially negative profitability due to R&D expenses and initial start-up costs which precede revenue from sales. This is the period of maximum funding requirements or maximum financial exposure and risk for an eventually profitable capital investment project.[2] For ultimately successful projects, this period is likely to be shorter where the target market demand is already established or is reasonably assured of developing (e.g., communications satellite services market) than in the case where the target market demand remains to be developed. Accordingly, the government can significantly mitigate the private sector's perceived financial risk on a venture and thereby influence the private sector capital investment decision with a policy instrument, such as deferred payment for launch services, which provides assistance particularly during the early years of a venture when financial risk and financial exposure is greatest.

In addition to influencing savvy equity investors who increasingly are placing more importance on expected net cash flow as a measure of a venture's projected performance,[3] a deferred payment option for reimbursement for launch services can greatly assist the project's ability to raise additional debt financing. Lending officers at commercial banks carefully consider a prospective borrower's pro forma cash flow statements.[4] Investment bankers also consider statements of projected cash flow to be indispensable.[5]

Preferred techniques for the private sector's evaluating the profitability of capital investment projects[6] take into account the timing of cash flows by placing a higher value on near term net cash flows and lesser value on net cash flows realized in the more distant future.[7] Therefore, a deferred payment option can be a very powerful policy instrument as long as deferred payment amounts are not escalated (e.g., for the opportunity cost of money to the U.S. Treasury) at rates in excess of the firm's after tax weighted average cost of capital to finance the project -- a theoretically improbable event in any case. The point is that to the extent the total amount of deferred payment reimbursements exceed, in real terms, the standard NASA launch price, the attractiveness of the concept to private industry would be reduced.

Some Variations of a Deferred Payment Provision

A deferred payment provision for reimbursement to NASA for Space Shuttle launch services can be structured into one of two broad types: (1) reimbursement according to a fixed schedule of not necessarily equal payments with some date certain, established relative to other milestones in the venture, for the final element of reimbursement, and (2) reimbursement according to an indefinite schedule of payment amounts with, accordingly, no date certain established for the final element of reimbursement.

The fixed schedule type of reimbursement plan is more in accord with installment sales of durables to end item consumers and with trade accounts receivable financing which is a common business practice in most business sectors in the United States, although such trade financing is usually of a relatively short term nature. The agreement NASA signed with the Geostar Corporation has characteristics similar to this type of reimbursement plan.

The indefinite schedule type of reimbursement plan more resembles a royalty arrangement and has some obvious variations. Royalties may be computed as a function of: gross revenues, profits before or after taxes, after tax return on equity or return on total investment, and as a function of other financial measures. A royalty type of reimbursement arrangement would appear to be more in accord with a capital investment project's ability to pay. This type of deferred payment arrangement is in accord with the agreement NASA signed with Space Industries, Incorporated (SII).

Each of these two broad types of reimbursement algorithms has advantages and disadvantages from the dual perspective of facilitating the commercial development of space and protecting the public trust. Escalation of deferred reimbursable amounts by the cost of money to the U.S. Treasury, to provide for repayment in real terms, can be applied in the case of either type of reimbursement plan.

Some advantages and disadvantages of these two broad types of reimbursement plans are as follows:

INDEFINITE SCHEDULE (ROYALTY TYPE)	FIXED SCHEDULE
Advantages:	
o Based upon the project's ability to pay, therefore increasing liklihood of the project's success.	o More in accord with sound trade credit financing principles.
	o Provides greater incentive to the firm's management to adhere to sound business principles.

- o Still allows firm to procure an effective loan at Treasury Bill rates.
- o Provides government with earlier warning of possible default.
- o Less uncertainty in NASA budget planning.

INDEFINITE SCHEDULE (ROYALTY TYPE)	FIXED SCHEDULE
Disadvantages:	
o Less assurance of NASA ever being fully reimbursed.	o Government competing with private sector financing.
o Questionable policy of government sharing disproportionately in the financial risk.	o More rigorous payment schedule could undermine eventual financial success of project if payment schedule not renegotiated.
o Auditing by government possibly required.	

A reasonable conclusion that might be drawn is that an indefinite schedule/royalty type of arrangement may be more appropriate where the target market remains to be sufficiently developed -- such as in the case of the market for free-flying platforms to house materials processing experiments or commercial production of materials. Conversely, the fixed schedule reimbursement arrangement may be more appropriate where a sufficiently large market either exists (e.g., communication satellite services) or has an excellent chance of developing rapidly when the technology is demonstrated to be successful (e.g., the potential market for radiodetermination satellite system industry services).

Government Risk Sharing[8]

Superimposed over these fundamental principles of trade credit that might be appropriately applied to a NASA deferred payment policy for launch services to encourage the commercial development of space are the following additional principles for U.S. Government risk sharing with the private sector to achieve a desired end result perceived to be of potential significant public benefit:

a. Government incentives both to private equity and to private debt money should be provided only to the extent required to attract the necessary capital.

b. A government risk sharing program should be simple and unambiguous to administer.

c. Government risk sharing policy should be fair, equitable, and preclude an effective assumption of all the risks by government. Government should bear only the extraordinary risks with private industry assuming all normal risks.

d. Government participation should be limited to the first generation of production size hardware using new technology.

e. Accordingly, there should be a provision for withdrawal of government participation when the risks have been reduced to manageable levels.

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APPENDIX 3

Analysis of the Impact of Two Deferred Payment Options

Office of the Comptroller

BASIC ASSUMPTION. The analysis evaluates the relative impacts of two deferred payment or "royalty" options on the STS program. In order to calculate these costs, a program of one flight each fiscal year from FY 1989 through FY 2003 (15 flights) was assumed to pay on a deferred payment basis. In order to simplify the analysis, a dedicated launch was assumed although it is recognized that payloads would most likely be shared payloads. This assumption does make a difference in the magnitude of total dollars involved, but the relative weights of trade-offs between pre- and post-launch reimbursement recovery are not affected. The result is initial cost and in later positive revenue flows that yield a stream that can be analyzed from a net present value perspective. This net present value analysis will reflect agency losses/gains associated with several royalty recovery (deferred payment) options.

Two pay-back options were evaluated. Both options use the $74 million (1982 dollars) price directed by NSDD 181 for post-FY 1988 launches. One option (A) uses this FY 1982 dollars amount escalated (at budget rates = 4.5 percent/annum) to the payment dates. The second option (B) is more involved and seeks to demonstrate the costs to the agency of receiving reimbursements after the costs of launching. In this scenario, the real year dollar (RY$) amounts normally are received on progress payments and are treated as a loan by the government to the customer at a nominal rate of 7 percent that would reflect the deficit financing costs that the government would incur. Each pay-back option assumed equal payment amounts beginning 2 years after launch and run on 5-, 10-, and 15-year schedules (suboptions 1, 2, and 3).

The pay-back options were compared against STS costs calculated on two different bases. One base (I) is the "opportunity cost" associated with post-launch reimbursement versus NASA's normal policy of pre-launch reimbursements spread over a 33-month progress payment schedule. This is the real cost of the launch if the launch could have been sold to another customer under the standard price and payment schedule. The second base (II) uses nominal marginal costs in lieu of price in making a similar comparison. This is the real cost if capacity is available with no other demand for the launch slot.

Each of the six pay-back suboptions against the two cost bases yields a stream of dollars that is either a net loss in a given fiscal year or a net gain. Two discount rates, 7 percent and 12 percent, were used in order to determine the net present values (NPV) of these various cash flows. The internal rate of return (IRR) for the break-even point where the NPV resulted in zero was also determined for each stream. Generally, the higher the IRR is for a break-even point, the greater is the likelihood of the government receiving a positive NPV for the cash flow, dependent on what the government assigns to the value of money.

SUMMARY RESULTS: Obviously, the lower the launch cost, in these cases, the marginal cost base (I), the greater the likelihood of high NPV's of a cash stream and the higher the IRR at the break-even point. Equally obvious, the pay-back option which reflects recovery of government financing costs (B) is more likely to result in higher positive numbers. See SUMMARY-1.

1.A. OPPORTUNITY COST/NORMALLY ESCALATED PAY-BACK

Scenario: Customer competition for available capacity.

The opportunity costs incurred compared to the FY 1982 dollars price escalated at budget rates to the payment dates resulted in positive cash flows to the agency for all three payment schedules. NPV's at 7 percent and 12 percent for all three payment schedules are all negative. The IRR in all cases is 4.5 percent. These results indicate that a return to the agency is positive only up to the point where reimbursements are escalated at the same rate as the agency costs.

	NASA RY$ Net	NPV @ 7%	NPV @ 12%	IRR
5-year	$515M	$124M	$223M	4.5%
10-year	841M	180M	305M	4.5%
15-year	1,220M	232M	371M	4.5%

1.B. OPPORTUNITY COSTS/LOAN-TYPE PAY-BACK

Scenario: Customer competition for available capacity.

By taking the RY$ amounts normally received from commercial payloads and treating them as loans to be amortized, one increases the out-year reimbursements back to the agency. In this option, this results in net positive cash flows to the agency. The NPV's at 7 percent were very close to zero and at 12 percent were negative. The IRR is similar to that of 1.A. in that it reflects the-rate at which the pay-backs were escalated; in this case, around 7 percent.

	NASA RY$ Net	NPV @ 7%	NPV @ 12%	IRR
5-year	$847M	$10M	$147M	7.0%
10-year	1,345M	10M	201M	7.0%
15-year	1,800	10M	242M	7.0%

II.A. MARGINAL COST/NORMALLY ESCALATED PAY-BACK

Scenario: Reduced competition for available capacity and/or government incentivization of commercial space R&D production.

With the same revenue stream as in I.A. and using marginal costs that are less than 50 percent of the opportunity costs in I.A., there is a greater net RY$ yield to the agency. Because of these significant cost changes, the net preset values at 7 percent and 12 percent are high as is the IRR.

	NASA RY$ Net	NPV @7%	NPV @12%	IRR
5-year	$1,765M	$549M	$243M	27%
10-year	2,091	493	161	19%
15-year	2,470	440	95	16%

II.B. MARGINAL COST/LOAN TYPE PAY-BACK

Scenario: Reduced competition for available capacity and/or government incentivization of commercial space R&D production.

With a greater revenue stream than in II.A. (and the same as in I.B.), all the values increase over those in II.A.

	NASA RY$ Net	NPV @7%	NPV @12%	IRR
5-year	$2,096M	$682M	$319M	31%
10-year	2,595M	682M	265M	24%
15-year	3,139M	682M	224M	21%

Finally, an analysis of pay-back option "B" was made on the sensitivity of increasing the pay-back loan rate by 36 percent from 7 percent to 9.5 percent, at which point that rate would be 5 percent higher than the cost escalation used (4.5 percent). This caused much higher NPV's and increased the IRR by about 2 percent for option 1.B. and 3 percent for option II.B (see SUMMARY-2). Increasing the cost escalation by the same ratio (by a factor of 1.36) and comparing that to the 9.5 percent reimbursable pay-back results in NPV's and IRR's at about the same levels as the initial analysis for options I.B. and II.B (see SUMMARY-3).

CONCLUSIONS: It is important to realize that, in the analysis, reimbursements were tied to the $74 million (1982 dollars) price, per NSDD 181. That price base was held constant and manipulated against two different costs bases. The four basic combinations of options (1.A., 1.B., 2.A., and 2.B.) vary markedly in terms of net real year dollars gains and all NPV's.

All options show positive returns up to at least the budget escalation level of 4.5 percent/annum. Reducing the calculation of cost to the agency by 60 percent (by using marginal costs) increases the IRR values by three to six times depending on the length of the pay-back cases. The longer the pay-back conditions, the lower the IRR; although for the options incorporating opportunity costs, the decrease is insignificant.

If the government is concerned only in recovering the marginal costs associated with a launch, then consideration of II.A. 1-3 and II.B. 1-3 is in order. Use of these cases would most likely be dependent on having an STS capability in excess of demand and/or commercialization projects that promise great benefits to the economy. In all cases, these scenarios show relatively high NPV values, due to the difference in (1) cost and price bases, and (2) escalated values. Halving the IRR (in R&D industries, the analytical IRR for go/no go decisions is usually halved when determining the value of projects and alternatives to incorporate implicit risk factors) indicates that the government could anticipate average returns on marginal costs of between 7 percent and 15 percent depending on the pay-back option selected and the anticipated length of the pay-back period.

A concern in recovery of only the marginal costs associated with a launch could also conceivably result in lowering the reimbursement price from $74 million (FY 1982 dollars) to some lower level. The closer that price is to marginal costs, the riskier is the proposition due to the reduction in NPV's and IRR. The discussion of results of I.B. 1-3 below where the base cost in equivalent to base price is also applicable to marginal cost recovery where the price is reduced to the level of marginal costs.

Cases I.A. 1-3 and I.B. 1-3 are the more conservative and the riskier of the various option combinations. This is because they are the cases where, by definition, costs (opportunity) are equivalent to reimbursements. Use of these scenarios would be appropriate when there is competition among STS classes of customers for STS capacity or where economic returns might not justify government subsidization of STS fixed costs. There is some nominal positive return at relatively low IRR values that basically mirrors the escalation and amortization rates used in the cost and pay-back cash flows. They are close to break-even scenarios if one were to assume that the initial net loss streams were financed through government debt. Break-even here would be dependent on a government financing rate being at a level roughly equivalent to the IRR values for each case.

Since there may be some risk associated with royalty payments from an R&D commercialization effort, it would probably be prudent to increase either the price or add points to the finance rate if options I.A. 1-3 or I.B. 1-3 were used in order to protect the government's investment.

CHALLENGER ACCIDENT IMPACT: No firm recovery flight rate has yet been established. However, it does appear there will be no STS flight before early 1988, and that flight rates will be significantly lower through FY 1990 than anticipated before the accident.

The backlog of payloads by that time will reach such proportions that introduction of new payloads, such as commercialization effort, would have to be carefully monitored and probably restricted. There are sizeable backlogs of all classes of payloads, including middecks, so even new small payloads will be subject to significant delays in that timeframe. New small payloads would almost have to be manifested on a space-available basis so that they do not affect the priorities of the classes of payloads already established.

STS costs are also not yet definitive for the time period and the agency has not completed a detailed review of resource requirements since the accident. It appears that a flight rate of 24/year may not be achieved by FY 1992. If previous total costs remain basically unchanged, a lower flight rate would result in higher average costs due to fixed costs being spread over fewer flights. The impact on marginal costs cannot be determined at this time.

II. Additional Reports Submitted in Response to Committee Requests From the 98th Congress

NASA SUPPORT

FOR

AN INTERNATIONAL GEOSPHERE BIOSPHERE PROGRAM

A REPORT

TO

COMMITTEE ON SCIENCE AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

OFFICE OF SPACE SCIENCE AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AUGUST 1985

NASA Support
for
An International Geosphere Biosphere Program

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INTRODUCTION

Background

In order to study the processes which lead to physical, chemical, and biological changes of the Earth on a global scale, it has been recognized by the scientific community that it is necessary to study the Earth as an integrated system. The NASA Administrator first proposed the concept of such an integrated interdisciplinary approach which would address long term changes in global processes involving the atmosphere, biosphere, and oceans at the Unispace '82 conference in Vienna, Austria in August 1982. This proposal for a "Global Habitability" Program was preceded by a summer study conducted at Woods Hole, Massachusetts in July of 1982 to investigate the feasibility of such a concept. Since that time, a number of additional workshops have been convened to develop further the rationale and the elements attendant to such a program.

In parallel with NASA's efforts to evolve a viable Global Habitability program, the National Research Council (NRC) of the National Academy of Sciences (NAS) has proposed the somewhat broader International Geosphere Biosphere Program (IGBP) which would extend the scope beyond that envisioned in the Global Habitability Program by including Sun-Earth interactions as well as interrelationships of the lithosphere with the oceans, biosphere, and atmosphere. The IGBP would be coordinated under the auspices of the International Council of Scientific Unions (ICSU) and would build upon existing international cooperative efforts such as the Middle Atmosphere Program, the Global Environment Monitoring Program, the World Climate Research Program, and other international research programs to strengthen existing Earth observation and monitoring systems. Prior to adoption by the ICSU of the proposed IGBP, the scientific scope and priorities of the proposed program are in the process of being more precisely defined. It is estimated that this process of definition will take at least two years from the time of ICSU general assembly meeting at which the concept of an IGBP was presented in Ottawa, Canada on September 25-27, 1984.

In its April 1981 "Report on United States Civilian Space Policy," the U.S. House of Representatives Committee on Science and Technology had recommended, prior to the evolution of the Global Habitability and IGBP activities, that NASA develop a program plan for a Global Resource Information System utilizing an interactive network of relevant data bases. This system would be based on information needs which the world science community would require to carry out such programs as Global Habitability and the International Geosphere Biosphere Program.

Purpose of Document

This report responds to the Committee's request, in its FY 1985 authorization report, that NASA submit to Congress a report that reviews NASA's support and contributions to the IGBP, potential missions that can be coordinated through IGBP, and a data management plan that carries out the intent to improve accessibility to global resource information.

NASA SUPPORT AND CONTRIBUTIONS TO IGBP

Support to IGBP Program Definition

Since the ICSU general assembly meeting in Ottowa, much of the IGBP definition process has taken the form of study committees and workshops. NASA has provided, and will continue to provide, financial support to the NAS for those activities involved in formulating the IGBP program. We have supported and participated in the two IGBP summer studies held in Woods Hole, Massachusetts in 1983 and 1984, and have also supported the NAS Board of Atmospheric Sciences and Climate (BASC) in its continuing deliberations regarding the IGBP program.

In addition to the above technical and financial support to IGBP committees and workshops, NASA has provided financial and technical support to a number of workshops and seminars dealing with specific elements of the IGBP, including:

- NAS/NRC "International Workshop on Spatial and Temporal Variability of Biospheric and Geospheric Processes: Research Needed to Determine Interaction with Global Environmental Change" (to be held in October 1985, in St. Petersburg, Florida).
- University Consortium for Atmospheric Research "Bilateral Workshop on Atmosphere/Biosphere Interactions" (held in July of 1985 in Boulder, Colorado).
- Columbia University "International Seminar Series on Global Habitability" (initial seminars currently scheduled for Buenos Aires, Argentina in August of 1985 and Colombo, Sri-Lanka in January of 1986).

NASA Internal Contributions to IGBP

In parallel with these IGBP program definition activities, NASA is proceeding internally to prepare for the implementation of research activities which will contribute to the IGBP. NASA has initiated the Earth Systems Science Committee (ESSC), a subgroup of the NASA Advisory Council, to review current Earth Science and Applications research, to define those areas that need further research, to define NASA's and the National Oceanic and Atmospheric Administration's (NOAA) role in such research, and to establish priorities for elements of the Earth Science and

Applications Program that need to be addressed in the next decade. The ESSC, using inputs from the Office of Science and Technology Policy (OSTP), the National Academy of Sciences and other workshop and committee reports, will also address the roles and efforts of other agencies, such as the National Science Foundation (NSF), the Department of the Interior (DOI), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the Department of State (DOS).

Implementation of the ESSC recommendations and NASA's contributions to the IGBP will require a comprehensive Earth Science Research Program involving space-based, suborbital, land-based, and sea-based measurements as well as laboratory, theoretical, and instrument and model development studies. Such a program will also require extensive national and international cooperation and participation. To implement such a program, NASA is continuing relevant ongoing programs such as Space Plasma Physics, Upper Atmospheric Research, Atmospheric Dynamics and Radiation, Oceanic Processes and Geodynamics; is expanding other relevant programs such as Global Biology, Tropospheric Chemistry, and Climate; is refocusing the Land Processes Program to address global research issues, and has initiated a new Interdisciplinary Research Program which will advance research in important areas lying between existing discipline areas or in those areas that are critically involved in more than one discipline.

As a first step toward implementing the Interdisciplinary Research Program, NASA has issued a "Dear Colleague" letter announcing new opportunities for scientists worldwide to participate in Interdisciplinary Earth Science Research. Three areas of interdisciplinary research have been chosen for initial study which are representative of particularly important problems on which progress can be made, while complementing ongoing activities in other related Earth Science programs. These three research areas will address the increasing trend in the atmospheric concentration of methane, study the extent to which changes are taking place in climatogically important properties of the land surface, and seek to develop a better understanding of the magnitude, variability, and rate of carbon fluxes in the oceans on a global scale.

POTENTIAL MISSIONS WHICH WILL SUPPORT IGBP

Current Missions

In order to adequately support the proposed IGBP, it will be necessary to maintain our current capabilities in operational as well as experimental satellite observations. The NOAA and Geostationary Operational Environmental Satellite (GOES) series of operational meteorological satellites, together with NASA experimental satellites, Nimbus-7 and the Earth Radiation Budget Satellite (ERBS) provide atmospheric and oceanographic data essential for continuous measurement of the neutral lower atmosphere dynamics and the earth radiation balance. ERBS is one element of a three-satellite system designed to provide the time and space sampling necessary for understanding the detail of the energy balance that exists between the Sun, the Earth, and space. The other two elements of the system are the operational polar orbiting meteorological satellites NOAA-F and -G, which are equipped with sensors identical to those on ERBS. The Earth's radiation budget is of critical importance to the study of climate change since it provides a direct measurement of the basic sources and sinks of the energy which drives the motions of the atmosphere and oceans.

NOAA also operates the Landsat satellites which provide the high resolution imagery required for land surface processes studies. Landsat sensors provide the spatial and spectral detail necessary to assess land usage and to classify terrestrial cover types. Determination of the spatial extent and distribution of the Earth's major land cover types is essential for estimating terrestrial inputs to global biogeochemical cycles and the earth's radiation budget. Vegetation indices derived from Landsat data provide useful estimates of crop yields and ecosystem productivity, factors centrally important to the carbon cycle. The extent of snow and ice cover, a major factor in the Earth's radiation balance and hydrological cycle, can be determined with Landsat data. Geomorphological and structural information from Landsat imagery is used to determine present day hydrological and climatic features as well as to make inferences about paleoclimates.

NASA's Shuttle Imaging Radar (SIR) experiments provide new information about terrestrial and ocean surface features. Surface roughness and topography, ocean waves and currents, soil moisture, and canopy structure are parameters important to the earth's energy balance and hydrological cycle which can be detected by radar. Radar data are used to delineate wetlands, believed to be significant contributors to trace gas fluxes, and, when combined with Landsat data, can greatly improve some land cover classifications.

The data from ongoing operational satellite systems such as Landsat, NOAA, and GOES and from experimental sensors and systems such as Nimbus, ERBS and SIR will be crucial to the implementation of the IGBP. For many elements of IGBP, historical data, as well as current data, from these operational and experimental satellites will be required in order to observe and assess long-term changes in global processes. NASA will continue to coordinate with NOAA, other government agencies, and the private sector to insure that such data will be available to the Earth Science research community.

Future Missions

In 1985, the Congress approved the Upper Atmospheric Research Satellite (UARS) Program and an improved NASA scatterometer to be flown on the U.S. Navy's NROSS satellite. In addition to these approved experimental flight missions, NASA is continuing engineering studies for the Ocean Topographic Experiment (TOPEX), the International Solar Terrestrial Physics (ISTP) Satellite Program, the Geopotential Research Mission (GRM), and enhancements to other elements of experimental programs which would contribute to the proposed IGBP.

Planned flight missions such as the Earth Observing System (EOS) will be necessary in future years to support the proposed IGBP. The EOS mission is the first NASA mission to be planned on a multidisciplinary basis. The ultimate goal of this mission will be to provide data leading to the understanding of how the Earth functions as a global natural system. Key themes within this goal are the improved understanding of the hydrologic and energy cycles as they relate to global climate, as well as the biogeochemical cycling of crucial nutrient elements. These themes are clearly at the intellectual core of IGBP. To address these research themes, related remote sensors in EOS will be assembled into functional units in order to obtain the research synergism which is possible through the simultaneous use of several instruments. The EOS instruments are grouped into three "packages" or groupings designed to maximize the synergy of observations. These packages are the:

> Surface Imaging and Sounding (SISP) - SISP is a package of instruments that includes moderate and high-spatial resolution imaging spectrometers, a multi-frequency microwave radiometer and a Lidar atmospheric sounder and altimeter. The focus of SISP is the investigation of the Earth's fluid and solid surfaces and interactions among the surface,

oceans, and atmosphere. Some observations of this class have been made and are continuing to be made, but improvements to these measurements are essential if we are to understand the functioning of the biosphere and related pysical and chemical processes. In particular, mapping geological materials, the understanding of biogeochemical cycles, the hydrologic cycle, and the world climate will require the types of new measurements to be provided by SISP.

Sensing with Active Microwaves (SAM) - SAM is a package that includes instruments utilizing active microwaves requiring high-inclination, near-polar orbits. SAM includes a synthetic aperture imaging radar (SAR), a radar altimeter (ALT), and a radar scatterometer (SCAT). All of these instruments are highly developed, although the multiple-look angle, multiple-frequency imaging radar capabilities have yet to be implemented. A high-inclination SAM mission will meet a number of scientific objectives in geology, agriculture, forestry, land cover, dynamic oceanography, and the cryospheric sciences. The ALT, SCAT and SAR form a particularly synergistic scienctific instrument package for ocean and ice applications.

Atmospheric Physical and Chemical Monitor (APACM) - The APACM package includes a doppler lidar, an interferometer for measuring upper atmosphere winds, instruments for determining the chemistry of trace elements and compounds, and instruments for measuring the solar flux and the particle and field environments. The focus of the APACM package is the chemistry and physics of the atmosphere.

Plans for implementation of the observing element of EOS center on the use of the new level of capability offered by the unmanned platforms within the Space Station program.

Future missions in geosynchronous orbit will support the IGBP by providing sustained views of the Earth system to evaluate change directly. Evolving strategies include making use of operational GOES data and flying additional instruments to augment future GOES payloads. The eventual use of specialized satellites in geosynchronous orbits optimized for multidisciplinary research purposes is also being considered.

DATA MANAGEMENT SUPPORT TO IGBP

Discipline Pilot Data Systems

In 1978, NASA initiated a coordinated data management activity aimed at making satellite data accessible on-line to the NASA Earth Science Research Community and providing the processing capabilities necessary to enable global-scale research using multisensor data sets. This activity involved the systematic development of improved techniques for data management, networking, data standards, and advanced processing systems. The task was structured around a series of discipline-specific pilot data systems.

Current pilot data systems (the Pilot Climate Data System and the Pilot Ocean Data System) address the needs of the atmospheres/climate and oceanographic communities, and a nation-wide communications network (the Solar Physics Applications Network) has been developed to serve the communications needs of the Solar Physics Research Community. A new pilot system oriented toward the land-related science research community (the Pilot Land Data System) is also being developed to demonstrate improved tools and techniques for researchers in the Land Processes disciplines of the Earth Science Research Community.

The Pilot Climate Data System and the Pilot Ocean Data System are early developments which were initially based on the concept of a centralized data repository, and a distributed user community. From the outset of its development, however, the newly initiated Pilot Land Data System is following the recommendations to NASA issued in a 1982 report of the Committee on Data Management and Computation (CODMAC) of the National Academy of Sciences. The CODMAC recommendations call for a distributed system concept in which the data are geographically dispersed and readily available to the full user community. To ensure relevance of data and system architecture, strong science user participation is encouraged in the definition of requirements throughout the development of the Pilot Land Data system.

Earth Observations Information Systems Pilot Data System

Building upon the above discipline-specific data pilot activities, NASA is addressing the needs of future Earth Science programs such as the IGBP through the development of pilot data systems which support a multidisciplinary approach to the understanding of natural phenomena and their dynamics. Increasingly, the data system requirements of Earth Science

Research involve comprehensive, multimission, multidisciplinary investigations that require global data sets from a variety of sources. In addressing these evolving requirements, NASA will continue the development of the discipline-specific Pilot Data Systems to understand their optimal use and capitalize on their best features. NASA will also initiate a new system, as a part of EOS, which will evolve these systems into a multidisciplinary information system. This system, the Earth Observing Information System (EOIS), will be designed to facilitate the access to environmental data sets held by NASA and by other agencies and institutions from various discipline areas.

During its pilot phase, the EOIS will build upon the knowledge gained during NASA's experience with the discipline Pilot Data Systems. By means of an integrated data cataloging system, standard interfaces and operating guidelines, diverse systems will be integrated to provide the capabilities to access and process multiple geographically dispersed data sets. Through communications linked work stations, scientists will then use the necessary procedures and algorithms to derive environmental science and resource information.

Global Resource Information Data Base

Recognizing the need for international cooperation in the acquisition, distribution, and analysis of the volume of data associated with programs such as the IGBP, NASA entered into an agreement in 1984 with the United Nations Environment Programme (UNEP) to participate in a pilot project to develop a Global Resources Information Data Base (GRID) within UNEP's Global Environmental Monitoring System (GEMS). GRID is an international cooperative pilot project to provide data to improve the study of global resource and environmental issues. The GRID approach consists of the development of methodologies for accessing and analyzing data on national, regional, and global scales using existing and future environmental data sets within the UN system, along with data from other sources such as the NASA data systems and those of other U.S. agencies such as NOAA and USGS. GRID will be structured as a globally distributed network of data bases linked by the Intelsat Communications Satellite System. NASA's participation in GRID consists of development of data systems hardware and software for the pilot-phase.

Operational Global Resource Information System

An operational global resource information system should ultimately build upon the coordinated capabilities which evolve from NASA's EOIS pilot system and UNEP's GRID pilot system. To ensure the harmonious evolution of the EOIS and GRID pilot activities, NASA will continue to encourage the coordination of the two activities through common membership in science steering committees and joint progress reviews. As GRID and EOIS each evolve toward an operational state, other international global environmental data bases may need to be incorporated into an overall global system to meet the science needs of programs such as the IGBP.

In addition to scientific and technical advisory commitees associated with all the above pilot projects, the National Research Council is currently conducting a study to examine critical issues which NASA must address to ensure that its information systems activities are conducted in a manner that will lead to a functional global resource information system. This study is being conducted by the NRC Board on Telecommunication and Computer Applications and is scheduled for completion in 1986.

PROPULSION CERTIFICATION REPORT

Background

The current congressional and administration policy toward commercialization of space activity and the introduction of commercially developed upper stages for the Shuttle appears to be having a significant impact on NASA's way of conducting its programs and activities, not only in the present but in the future as well.

As evidence of the above, one has only to refer to the impact caused by the PAM failures on Shuttle manifesting and launch scheduling. Further confirmation of the impact may be obtained in NASA planning for downstream missions--VRM, MO, and TDRS, to name some of the obvious ones--and is also being affected by the commercial activity in upper stages. Procurements for these NASA missions are being conducted in a competitive process rather than the directed procurements that have been justified and utilized in the past, prior to the existence of commercially developed upper stages.

The Subcommittee on Space Science held hearings to conduct a review of Shuttle requirements, operations, and future plans in order to assure that the system will continue to evolve into an effective, responsive, cost-effective space transportation system. In its report summarizing witness's testimony and discussion of key issues raised during the hearings, the Subcommittee recommended that the Administration give serious consideration to the proposal made by civil users that the government institute an independent and continuous review of the design, manufacture, qualification, and test of all propulsion systems produced within the United States, i.e., in essence, "certifying" these systems for civil and foreign users.

The purpose of this report then is to respond to the recommendation by the Subcommittee and address "certifying" all propulsion systems produced within the United States.

Discussion

A summary of potential upper stages for use with the Shuttle is shown on the accompanying table (Table 1). This list shows that there are more than 12 stages available or which will become available in the next several years for space transportation users. About two-thirds of the Shuttle's flights require additional propulsion to take the spacecraft from low Earth orbit to a desired orbit or position in space. It is meeting this requirement that has generated the activity in upper stages. The activity is nourished by the general acceptance that some, if not all, of this activity can and should be done on a commercial basis; that is, an entrepreneur can assume responsibility and risk for the development of an upper stage and earn a profit through its use.

In discussing the question of "certification" of these upper stages, one should address the idea that there should be some gain that would be achieved by the certification action. One obvious concern is risk, since the commercially developed upper stage is inserted between a satellite customer and the STS system, in effect becoming an extension of the Shuttle. Any failure of the commercial system endangers the STS schedule and its operating revenue plan as well as being considered a detriment to NASA's reputation and technical image.

It should be recognized that any cargo being carried in the Shuttle, whether it be payload or payload plus propulsion, undergoes a rigorous safety review. All payloads using the system are subjected to a uniform set of basic safety and interface requirements. The intent of this safety policy is to identify any hazard potential of the payload and to require that the basic payload design assures elimination or control of any hazard to the Orbiter, crew, or other payloads.

The payload supplier is responsible for assuring the safety of any hardware proposed for use in the Shuttle. The payload supplier should also provide assurance of the compatibility of the payload with the Shuttle. In summary, the major goal is to provide a payload with minimum hazard, including damage control, containment, and isolation of potential hazards.

Although the payload suppliers are required to meet NASA safety requirements, NASA has no responsibility for commercial payload performance. NASA would, of course, like to see a success for every payload it launches, but payload reliability and quality is the sole responsibility of the payload supplier. It is not NASA's intent to impose independent reliability and uality assurance requirements through the Shuttle safety reviews, nor is it intended to assure a high probability of mission success for the payload.

The value to NASA in adopting the Shuttle safety review is obvious--the reusable Shuttle is protected insofar as it is possible against inadvertent or other events caused by the spacecraft from occurring while in the cargo bay and endangering the Shuttle itself. The safety system was 100% effective for the 17 flights to date.

Given this set of established practices, then, applied uniformly to all payloads (and here payloads is used in a generic sense applying equally to a payload or its accompanying propulsion system), one again addresses the need for additional activity, i.e., "certification" of the propulsion system. What has been the experience to date?

Three variations of upper stages have been launched from the Shuttle. Two variations were commercially developed (PAM-D, and Syncom), and one was a government directed development (IUS). All three were relatively "new" developments undertaken for enhancement of the Shuttle and requiring new fields of development to be explored. All three developments experienced difficulties or anomalies in flight.

While this statement is of little comfort to the particular user whose mission failed, two of the failures or anomalies occurred in subsystems that were independent of any changes for compatibility with the Shuttle--they occurred in subsystems which were pushing new "state-of-the-art" developments and reconfirmed that space is risky business. They, along with the third, could (or would have) occurred on an ELV if that subsystem had flown first on an ELV.

The three classes of upper stages that have been launched from the Shuttle are, in fact, examples of the three options for certification that NASA could choose. The first is a government-sponsored development wherein the government through its contract with the developer provides direction, review, and assessment of the upper stage being developed. The Inertial Upper Stage (IUS) was developed under government contract. The second variation is a development conducted under a technical monitoring arrangement which provides NASA with sufficient insight to assess the upper stage's technical adequacy for its intended purpose and availability when needed. The Payload Assist Modules (PAMs) were developed under this arrangement by an agreement between NASA and the developing contractor. The third variation is a development conducted solely by the contractor with no government assistance. Here, a developer sees a potential need and takes action to meet it, risking his own funds in the development. The Syncom was developed under this approach.

IUS Experience

The IUS has flown twice--once launched from an expendable launch vehicle and once from the Shuttle. The first was successful; the second experienced problems in flight, and the mission was declared successful only after the spacecraft was able to correct the orbit in which it had been improperly placed.

Reviewing the government sponsored IUS development program, two agencies combined their efforts in conducting this program. Quality and reliability programs were vigorously pursued; comprehensive design reviews and readiness reviews were employed throughout the program; material and piece parts were procured to high reliability government specifications. The government conceived, initiated, and directed, and is continuing to direct, this program--certainly "certification" at a high level.

PAM Experience

As indicated above, the PAM projects were conducted as a commercial initiative with agreement having been reached that NASA would monitor the development program. Eighteen PAMs were successfully launched--thirteen on ELVs and five from the Shuttle--when two failures occurred.

Having monitored one contractor's commercial development (PAM-D), it would be difficult for us to be critical of his development program. In fact, when another independent government review was made of his commercial product for government use, his quality and reliability practices were rated "exemplary" and, yet, the failures occurred. Further, the government closely followed the contractor's investigation into these failures as well as his recommendations and implementation of corrective action.

The investigation was conducted in a professional and dedicated manner, indicative of the contractor's commitment to the program. There were no perceived differences in the conduct of the investigation than if it had been a government program. Nine successful flights have been conducted without failure since the resumption of flight after the failure investigation. One conclusion became clear during the investigation: the cause of the failure could not have been detected under the then accepted and recognized acceptance procedures or criteria. The contractor subsequently adapted Computer Assisted Tomography (CATSCAN) as part of his acceptance criteria in detecting good or bad nozzles.

Syncom Experience

The remaining system to be discussed was a pure commercial development in that the contractor designed not only the spacecraft, but also an integral propulsion system to place his spacecraft into the desired orbit. Integral as used here means that the design of the two subsystems--spacecraft and propulsion unit--form the whole, with neither able to operate without the other.

The Syncom manufacturer has had extensive successful experience in spacecraft development. Further, he has demonstrated over the same period his capability of integrating propulsion units into his spacecraft, delivering whole systems in commercial ventures. The extension of his capability to perigee applications appeared well within his capability. After two successful attempts, his system experienced a failure on the third try.

Summarizing the above experience, all three systems had difficulties. Two of the systems, IUS and PAM, were subjected to certification of the type suggested by the Subcommittee. The third system, Syncom, was free of government review, depending upon methods utilized in long and successful commercial spacecraft programs.

Certification Approach

The extremes of certification can vary from none, as exemplified by Syncom, or high, as exemplified by the IUS or Shuttle/Centaur which are government directed developments. For industry-developed stages, we considered a program as outlined in Enclosure 1. In this approach, levels of certification, NASA review, guidance, and reasonable assistance would be provided to the developer through the conduct of his program, but the cost of this certification and assistance would be borne by the developer.

In this program, NASA would have to participate in requirement reviews, preliminary and final design reviews, test program levels, and uality and reliability efforts to adequately perform the desired certification. The frequency of inspections, coordination, and reviews would require significant funding and personnel resources, with an inability to accurately predict the timeliness or scope of the resources. We believe that NASA would have problems with the adequacy of enforcement and procedures for compliance.

Since the cost for this would be borne by the developer, we believe that he would consider it objectionable. In an environment of competitive profit making activity, dependency on certification by the government would introduce an uncertainty in cost which would discourage rather than encourage commercial ventures. The certification process would permeate the commercial development from reviews to preparation in meeting requirements. It would be considered in conflict with the true spirit of commercial development.

The Subcommittee apparently recognized that a certification role for NASA would be a new one and cautioned that any "initiative incorporate a minimum amount of regulatory activity." The program outlined above, to be effective in providing a basis for certification, would have to be strictly enforced; in effect, it would involve government participation through the life of the program much the same as exists today in the IUS or Shuttle/Centaur programs. For these reasons, this depth of involvement is not recommended.

The government is now involved in the development of a range of upper stages:

- Small payloads are delivered by PAMs; the development activity is monitored by agreement with the government.

- Intermediate payloads can be delivered by the Transfer Orbit Stage (TOS). This stage is in development as a commercial venture, monitored by NASA under the terms of a NASA/developer agreement.

- Larger payloads are (or will be) utilizing the IUS or Shuttle/Centaur stages; these are government developments.

Within this overall range of capability, we are monitoring programs in each of the spacecraft classes.

Recognizing that the Subcommittee desired serious consideration be given to the proposal made by civil users, we are considering a policy for upper stages--Enclosure 2. It indicates that the government would either pursue on its own or monitor a commercial development in each of the spacecraft classes; that any effort would be on a monitoring basis, to be paid for by the user, and would depend on the cooperation of the developer rather than the threat of noncertification.

Conclusions

- The Shuttle safety review appears adequate protection for the Shuttle to date, and we have no reason to believe that it will not continue to do so.

- A full certification of upper stages is not desirable. It is costly, could be duplicative, and most likely would be unenforceable from a compliance standpoint. Further, it would require a significant amount of regulatory action by NASA to make it effective, counter to NASA's present role.

- Most classes of payloads are covered by existing government or government monitored programs.

- The proposed policy on upper stages makes the service available to those developers or manufacturers who desire it, thus enhancing its effectivity.

- Under the overall plan, the government is protected. It can develop the stages it needs for its own use, monitor developments in the private sector because they are requested to provide these services or because the government believes there is adequate quid-pro-quo.

UPPER STAGES (EXISTING)

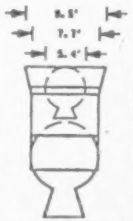
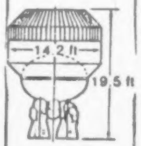
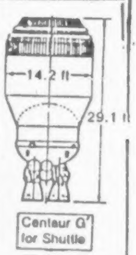
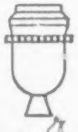
CHARACTERISTICS	PAM D	PAM A	PAM D-II	IUS (TWO-STAGE)	CENTAUR G	CENTAUR G'
STAGE: MANUFACTURER • LENGTH FT • DIAMETER FT	MDAC 7.75 4.4	MDAC 7.5 4.4	MDAC 6.5 3.3	BAC 16.4 9.5	G.D. 19.5 14.2	G.D. 29.1 14.2
ENGINE: MANUFACTURER • TYPE • NUMBER • FUEL • COMPOSITION	THIOKOL (STAR 48) 1 SOLID TP-H-3340	THIOKOL (MINUTE MAN 3) 1 SOLID ANS-3066	THIOKOL (PAM D-II) 1 SOLID	CSD L-MOTOR 1 S-MOTOR 1 SOLID HTPB	PRATT-WHITTNEY RL10-3-3B 2 $LH_2 \& LO_2$ 6:1	PRATT-WHITTNEY RL10-3-3A 2 $LH_2 \& LO_2$ 5:1
TOTAL THRUST LBS SPECIFIC IMPULSE SEC BURN TIME SEC	14,900 285.6 85.0	35,720 274.3 55.5	17,600	41,621 17,163 292.6 304.1 133 104	30,000(2X15,000) 440.4 436	33,000(2X16,500) 446.4 603
STAGE: PAD WEIGHT LBS • IMPULSE PROPELLENT WEIGHT LBS • BURN-OUT WEIGHT LBS • AIRBORNE SUPPORT EQUIP. WT LBS	4,816 4,400 416 2,505	8,261 7,560 701 4,590	12,270 } 7,692	32,542 21,400 6,060 2,476 2,328 0,111	37,517 25,718 7,799 5,126	31,760 43,085 6,760 9,748
PAYLOAD^{1}: TO GEO - ONE WAY STAGE (2,2a) LBS • TO GEO TRANSFER ORBIT (GTO) LBS	~1400 (REQS. KICKSTAGE) 2,750	~2200 (REQS. KICKSTAGE) 4,235	~2000 (REQS. KICKSTAGE) 4,160	4818	10,200^{2} 10,200^{2A}	20,400^{2} 14,560^{2A} 26,000
ILLUSTRATION: 1. REF: 28.5° INCLINATION & 150 N.M. CIRCULAR 2. STAGE PROPELLENT FULL 2a. STAGE, PROPELLENT, PAYLOAD, AND A.S.E. LIMITED TO 65K	 PAM D	 PAM A	 PAM D-II	 IUS (TWO-STAGE)	 CENTAUR G	 CENTAUR G'
SCHEDULE: START DATE • OPERATIONAL DATE • LAUNCH RATE (FLTS/YEAR)	1976 1982 TBD	1977 TBD	1982 1983 TBD	1978 1982 TBD	1982 1987 TBD	1982 1986 TBD
TYPE OF DEVELOPMENT SPONSOR	COMMERCIAL DEVELOPMENT MDAC	COMMERCIAL DEVELOPMENT MDAC	COMMERCIAL DEVELOPMENT MDAC	US GOVT USAF	US GOVT NASA	US GOVT NASA

TABLE 1.

Q291.ARI.7

UPPER STAGES (PROPOSED)

CHARACTERISTICS	OMV	IRIS	SCOTS	DTS	STV	TOS	TOS/AMS
STAGE: MANUFACTURER • LENGTH FT • DIAMETER FT	TO BE SELECTED 3.3 15.0	AERITALIA 7.5 4.9	RCA ASTROTECH 9.1 6.0	MDAC 30.3 10.5	BRITISH AEROSPACE IN STUDY	MMC 10.8 11.3	MMC 16.95 10.0
ENGINE: MANUFACTURER • TYPE • NUMBER • FUEL • COMPOSITION	8 N_2O_4/MMH 1:1.65	BPD DIFESA SPAZIO 1 SOLID HTPB	WASATCH 63-E 1 SOLID HTPB	OMS-E N_2O_4/MMH 1:1.65	N_2O_4/MMH	CSD 1 SOLID HTPB	1ST STAGE CSD 1 SOLID HTPB 2ND STAGE ROCKETDYNE 1 N_2O_4/MMH/N_2O_4 1:1.65
TOTAL THRUST LBS SPECIFIC IMPULSE SEC BURN TIME SEC	800 310	290.6	22,500 298 325	6,100 301	~310	41,621 292.6 153	41,621 2,650 291.4 315 153 1,100
STAGE: PAD WEIGHT LBS • IMPULSE PROPELLENT WEIGHT LBS • BURN-OUT WEIGHT LBS • AIRBORNE SUPPORT EQUIP. WT LBS	10,496 6,566 3,930 110	4,035 3,467 368 2,105	16,063 8,983 1,062 3,700	51,100 44,105 6,985 4,350	IN STUDY	24,116 21,400 2,623 3,610	34,443 21,400 8,570 2,043 1,320 6,175
PAYLOAD[1]: TO GEO - ONE WAY STAGE (2, 2a) LBS • TO GEO TRANSFER ORBIT (GTO) LBS	~1500 FPS FOR DELIVERY AND/OR RETRIEVAL WITHIN 1500 NM OF THE SHUTTLE	1,000 1,982	2500 (REQS. KICKSTAGE) 6,500	7,500 18,500	ESTIMATED 2,500–4,000 4000–8000	N/A 13,000	6,500
ILLUSTRATION: 1. REF: 28.5° INCLINATION & 150 N.M. CIRCULAR 2. STAGE PROPELLENT FULL 2a. STAGE, PROPELLENT, PAYLOAD, AND A.S.E. LIMITED TO 65K	OMV	IRIS	SCOTS	DTS	IN STUDY	TOS	 TOS/AMS
SCHEDULE: START DATE • OPERATIONAL DATE • LAUNCH RATE (FLTS/YEAR)	1986 1990 TBD	1987 TBD TBD	1984 1986 TBD	1986 TBD TBD	TBD	1982 1986 TBD	1983 1987 TBD
TYPE OF DEVELOPMENT SPONSOR	US GOVT PHASE B STUDIES LTV, MMC, TRW	COMMERCIAL DEVELOPMENT ITALY	COMMERCIAL DEVELOPMENT RCA ASTROTECH	COMMERCIAL DEVELOPMENT ASTROTECH INC	COMMERCIAL DEVELOPMENT SCOTT SCIENCE & TECHNOLOGY	COMMERCIAL DEVELOPMENT ORBITAL SCIENCES CORP	COMMERCIAL DEVELOPMENT ORBITAL SCIENCES CORP

UPPER STAGE CERTIFICATION

1. Every Upper Stage flying on two or more Shuttle flights must be STS Type Certified.

2. Preliminary STS Type Certification is granted at CDR.

3. Final STS Type Certification is granted at the Stage Acceptance Review of the first flight article.

4. STS Type Certification is granted on the ability of the Upper Stage to perform a predeclared (at PDR) Class of Missions with acceptable levels design margin, testing, quality control, and reliability as determined by the assigned organizational element within NASA.

5. Mission Certification is granted at the Flight Readiness Review and will include a Review of the STS Type Certification by NASA Senior Management as required.

6. Mission Certification is granted on the basis that the subject mission is contained the Class of Missions appended to the STS Type Certification.

7. An Amended Type Certification is required to expand the predeclared Class of Missions appended to the original Type Certification.

8. A Mission Certification cannot be granted for a mission outside the predeclared Class of Missions appended to the current STS Type Certification.

9. No Shuttle mission assignment can be made until an Upper Stage has been granted a Preliminary STS Type Certification which has the proposed mission contained in the predeclared Class of Missions.

10. The requirements for STS Type Certification are contained in the Shuttle Upper Stage Regulatory Requirements Document.

11. An Experimental Type Certification may be granted to Upper Stages to be used on only one mission provided STS Safety Requirements are met.

12. An Experimental Type Certification lapses and may not be renewed after one mission.

13. The cost of Type Certification will be borne by the developer.

14. NASA will provide guidance and reasonable assistance to the developer in meeting the Type Certification Requirements.

15. No compromise or waiver to the Shuttle Upper Stage Regulatory Requirements may be granted when a Shuttle launch delay might result either on the planned or subsequent flight.

Enclosure 1

GENERAL POLICY

- o NASA encourages private sector development, supply and operations of upper stages.
- o It is NASA policy that private sector developed/supplied upper stages be funded with non-government resources.
- o NASA will actively pursue government funded stage development and production to assure timely availability of adequate systems to accommodate mission classes not being developed/supplied by the private sector.
- o The private sector developer/supplier shall be responsible for his product and contracts and success or failure will be determined by supplier performance and business merits of the venture.

TECHNICAL MONITORING

- o NASA will offer technical advice and consoltation to the private sector based on available NASA expertise and experience. NASA will recover associated costs.
- o It is NASA's desire to technically monitor at least one development/operation of each upper stage spacecraft class.
- o NASA will pursue technical monitoring agreements between NASA and private sector developers under the following circumstances:
    - When requested by the private sector developer
    - When of specific benefit to NASA and NASA objectives
    - When a particular class of upper stage has no NASA overview
- o NASA does not require technical monitoring arrangements with the private sector

ENCLOSURE 2

- NASA will enter into monitoring arrangements with more than one developer/supplier in a given upper stage class if there are NASA benefits.
- Technical monitoring arrangements shall provide NASA sufficient insight to assess upper stage technical adequacy for intended purposes, and availability when needed.
- NASA desires sufficient cost/price insight from each developer/supplier to understand the customer's launch system prices and areas wherein U.S. competive posture could be improved. NASA does not require cost/price data, except in certain specific instances.
- NASA activities with private sector developer/suppliers shall be in a manner such that the supplier clearly retains responsibility for his product and success or failure is determined by supplier performance and the business merits of the venture.

TECHNICAL PROBLEMS/RESOLUTIONS

- In general developer/supplier will resolve problems without NASA involvement.
- NASA will provide, as available on a non-interference basis, advise, consultation, assistance, and recommendations to private sector developers/suppliers for resolution of technical/engineering problems
- NASA will recover "additive" costs for the above
- When specific assistance is requested, cost for NASA efforts will be borne by the requestor.
- NASA costs for efforts that benefit a community at large (e.g. space craft) will be recovered from that community.
- NASA will bear the cost of efforts taken of NASA's own initiative when those efforts are specifically for the benefit of NASA or the national interests.
- Under circumstances which threaten to seriously disrupt NASA operations, which impact NASA missions, or which have a significant impact on national interests; NASA will of it's own initiate actively pursue timely resolution.

PURCHASING

- NASA encourages upper stage private sector supplier sales directly to users/customers without NASA participation.

- Contract prices and terms/conditions are a matter between the private sector supplier and buyer
- NASA will purchase private sector developed upper stages as an agent for NASA customers when requested by NASA customers. NASA will recover associated NASA costs.
- Contractual arrangements will be in accord with customer, NASA, and supplier requirements at the time of contract award.
- NASA purchases as agent for a customer shall require adequate data for NASA to evaluate supplier stage performance, availability on schedule, and cost/price.
- NASA will in general purchase private sector developed/supplied upper stages for NASA missions when in the best interest of the agency.
    - NASA may in certain instances consider only government stages for NASA missions.
    - NASA will evaluate private sector supplied stages and government stages for NASA missions.

ASTROPHYSICS AND THE SPACE STATION

VOLUME 1

EXECUTIVE SUMMARY

Our nation is embarking on yet another high adventure in space. In January 1984, in his State of the Union address to the Congress and citizens of the United States, President Reagan announced a bold initiative: the establishment of a Space Station as a permanent manned presence in space. Within a decade, this Station will come into service as a center for shaping our future activities in space.

The use of the Space Station for research is of particular interest to the astrophysics community. We are now identifying the ways in which the Space Station can serve us as an observing platform, service center, assembly base, and support node for the missions planned for the near future. As advances in technology enable us to study the sky with greater clarity and precision, the Space Station will provide great opportunities for increasing our knowledge of the universe.

Astrophysics Needs are Matched to the Space Station

The Space Station will be important to astrophysics for a number of reasons. First, astrophysics as a scientific discipline can meet most of its scientific objectives with missions in orbits that are compatible with the Space Station (i.e., 28.5-degree inclination at varying altitudes). Because most of the astrophysical information comes to us in the form of radiation (such as visible light), which reaches the Earth equally well at any latitude, orbit inclination is not the most important consideration for most of what we do. By far, the major issue in astrophysics is simply to get above the atmosphere which obscures most of the radiation from celestial sources. Even when the radiation can penetrate to observatories on the Earth's surface, the atmosphere acts as a glowing background against which one can not do astronomy effectively.

We expect that the Space Station will be a versatile multipurpose facility that can serve astrophysics in several important capacities. For example, astrophysicists contemplate using the manned Space Station as an observatory base to carry certain instruments. We also envision using the manned Space Station to service satellites; of particular interest are the observatories which are designed and justified on long-life operations with servicing to repair failures and to upgrade technology. Astrophysics can use the manned Space Station as a base of assembly. At least one project (the

Large Deployable Reflector) has been identified and is being actively pursued in a study/technology development phase; it probably would not be feasible without extended assembly operations on orbit. The Space Station can also serve as a transportation hub and service node for platforms, opening the possibility of making truly permanent observatories for infrared and x-ray astronomy and of putting a whole fleet of Explorer-class payloads into service. It looks very attractice and feasible to maintain and recycle these small platforms from the Space Station. Finally, the Space Station could enhance spacecraft operations by augmenting support functions--acting as a communications node, for example.

Content of the Reports

This set of reports is intended to address near-term scientific priorities for the Astrophysics Program in the context of the new Space Station. The reports have been developed to highlight those key pieces of the Astrophysics Program that fit well within the Space Station concept. In these reports, the strategies outlined in the National Academy of Sciences report, Astronomy and Astrophysics in the 1980's (also known as the Field Committee Report), are implemented by using the Space Station effectively. Thus, this set of documents provides for carrying out the most imperative scientific objectives in astrophysics.

Workshop on Astrophysics Utilization of the Space Station

The reports were developed by convening key leadership from the scientific community, industry, and NASA to work together in defining strategies and concepts for meeting our announced scientific objectives and implementing the Agency's program plans with Space Station utilization. Individuals who are expert in the various areas were identified during late spring of 1984, preliminary drafts of these final products were prepared, and a group of approximately 100 scientists and Agency representatives assembled in a workshop on June 20 and 21, 1984, at the Goddard Space Flight Center in Greenbelt, Maryland. The drafts were discussed by groups of representatives, each group focusing on the concepts in one of the reports. The concepts and ideas were also exposed and discussed before the entire group in large plenary sessions. What has emerged from this endeavor is a conceptual foundation for astrophysics utilization of the Space Station. We intend that NASA use these documents as guidebooks for technical and programmatic considerations during Space Station definition.

SPACE AND SPACE ASTRONOMY: THE NASA ASTROPHYSICS PROGRAM

We are stargazers. Since ancient times, we have studied the heavens to understand the mysteries of the universe, its organization, origin, and history. Only for the past 25 years, a blink of the eye in the course of human history, have we been able to study the stars from a vantage point in space. Yet in this brief interval, we have made remarkable progress toward answering the questions that have eluded us for centuries. We have also raised new questions and found the universe to be a far more interesting and active place than we had ever imagined.

Today our study of the universe blends ancient astronomy, modern physics, and state-of-the-art technology. While we still aim to explore and understand, to discover and analyze the universe, our scientific objectives and the instruments required to meet them have grown increasingly elaborate. We now follow a strategy for examining the universe methodically to coax out its secrets: from initial surveys in different parts of the spectrum, we move toward long-duration, detailed studies using the observatories. Our goals are to understand the origin and evolution of the universe and the basic physical laws governing the phenomena that we observe there. The nearest star, our Sun, is a Rosetta stone as we seek to understand how energy is generated there and transported through space in the solar wind.

Space Astronomy

In our time, we have risen above the obscuring atmosphere and pursued our research in space. No longer confined to peering at the stars through a "dirty basement window", we have achieved in space a vast view of the universe. With instruments borne on balloons, rockets, and free-flyer satellites, we have achieved greatly improved sensitivity, resolution, and wavelength coverage. Research in space has revolutionized the practice of astronomy and spawned the many new disciplines of astrophysics. A new major challenge is the utilization of a permanent base for the appropriate astrophysical research.

The primary and obvious advantage of doing astrophysics in space is that only there do we have access to all channels of information in the electromagnetic spectrum. Celestial objects emit radiation across the spectrum from lowest-energy, longest-wavelength radio through infrared, visible, ultraviolet, x-rays and highest-energy, shortest-wavelength gamma rays. Virtually all of our knowledge of celestial objects is derived from observation of electromagnetic radiation. Each wavelength band carries unique information about its source and about physical processes occurring there. Of the 20-odd decades of electromagnetic radiation that reach the top of the atmosphere, only 5 decades penetrate to the ground. Thus, on Earth we have access to a mere fraction of the available information; to open all the channels and learn more, we do our research in space. Even for those regions of the spectrum where the atmosphere is relatively transparent, such as the radio and visible bands, it is enormously advantageous to place instruments in space beyond the distorting atmospheric interference.

Telescopes for Space Astronomy

Those unfamiliar with astronomy often ask why we need so many different kinds of telescopes. Why are not the Palomar and Hubble telescopes, among the largest on Earth and in space, sufficient? The answer, of course, is that they are optical telescopes and optical astronomy reveals only part of the universe (some would say only the "normal" universe). Astronomy in visible wavelengths principally shows us the stars. Even more interesting sights--bizarre objects and cosmic explosions--can be "seen" by other kinds of telescopes sensitive to the invisible wavelengths. Visible light is not the primary output of pulsars, quasars, supernovae, and the like; we learn much more by investigating their radiation in other wavelengths.

Infrared radiation, for example, is emitted from relatively cooler objects, such as the clouds of dust where stars are born or the cinders of burned out stars. X-ray radiation, on the other hand, indicates the presence of gases heated to millions of degrees and catastrophic events often characteristic of the death of stars. Mysterious objects known as quasars, pulsars, and black holes emit X-rays profusely. Gamma rays are released by the most energetic events. As we proceed with our inquiry into the nature of the universe, we must investigate the sky in all wavelengths. Detection in each spectral region requires an entirely different kind of instrument. Separately or in concert, these different instruments are essential to astrophysical research.

Unresolved Questions

In the past 25 years of space astronomy, we have vastly increased the catalog of known celestial objects. For example, we have identified at least 5,000 X-ray sources and a quarter of a million infrared sources, and there is no reason to think our lists are complete yet. We have made startling discoveries about probable events in the universe, and we have pushed the frontiers of knowledge further and deeper into time and space. Yet the successes of our recent work, impressive as they are, have also shown us how much we do not yet understand. Quasars, for instance, are remarkable objects the size of our solar system that emit as much energy as an entire galaxy; but we cannot yet explain the process or mechanism responsible for this powerful phenomenon. There are enough unanswered questions left to engage our attention well into the next generation.

The National Academy of Sciences report Astronomy and Astrophysics for the 1980's presents the major unresolved questions before us today and suggests appropriate strategies for attacking these problems. Before we consider how we might use the Space Station to implement those strategies, let us briefly review the general issues in current astrophysics research:

- Violent events: What exactly are supernovae, pulsars, black holes, and quasars? What is their structure? What physical processes produce such tremendous energy?

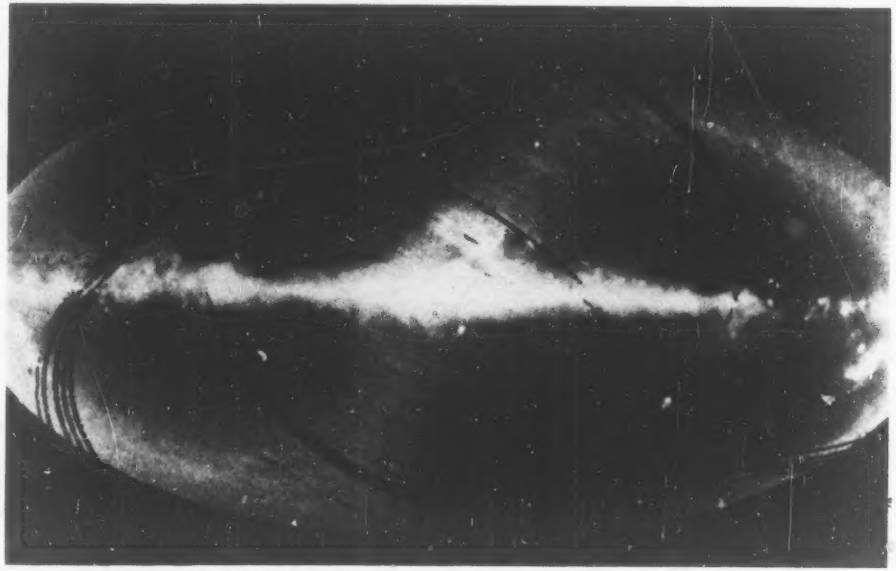


FIGURE 1.1. PICTURE OF THE SKY, TAKEN WITH INFRARED LIGHT.

Infrared radiation, with wavelengths of about 10^{-5} m, is invisible to the human eye. Areas that emit infrared radiation are often clouds of dust where stars are forming.

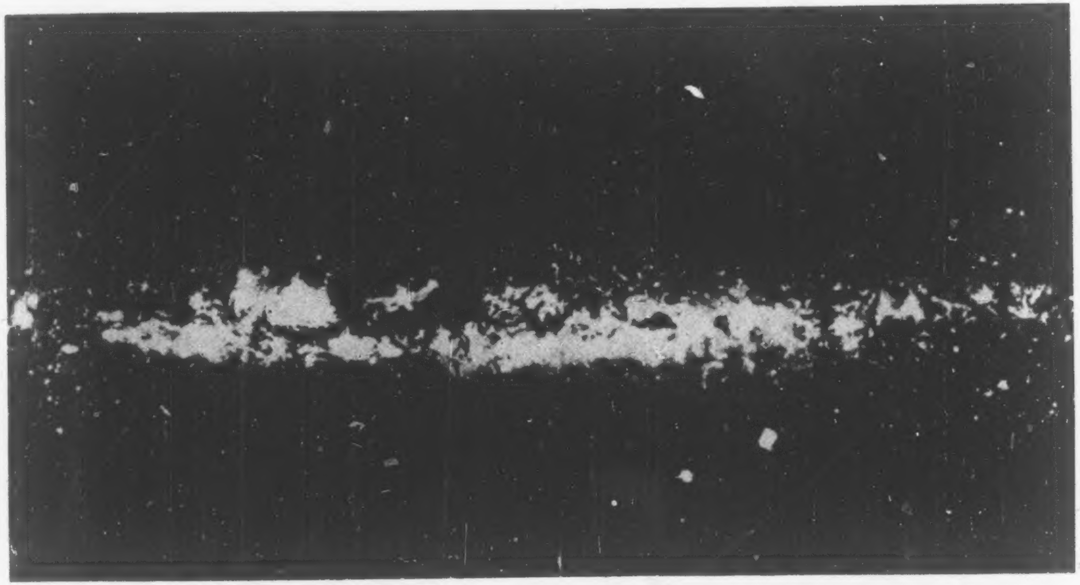


FIGURE 1.2. PICTURE OF THE SKY IN VISIBLE LIGHT

Visible light, with wavelengths of a few times 10^{-7} m, comes primarily from nearby visible stars and from galaxies above and below the Milky Way.

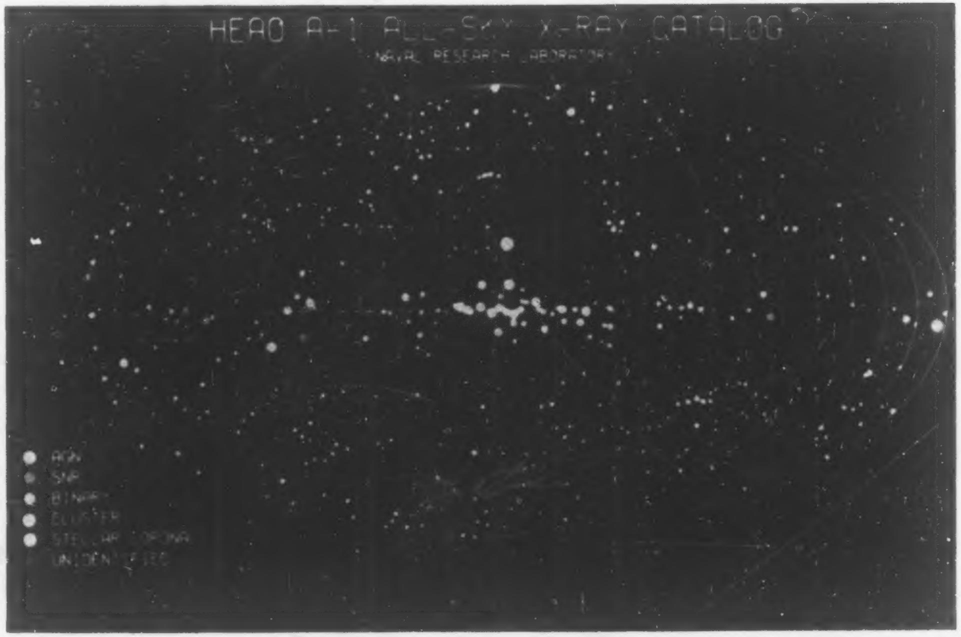


FIGURE 1.3. PICTURE OF THE SKY IN X-RAYS

Quasars, pulsars, and black holes emit x-rays, which have wavelengths of about 10^{-10} m. X-rays indicate areas of extremely high temperature and catastrophic events.

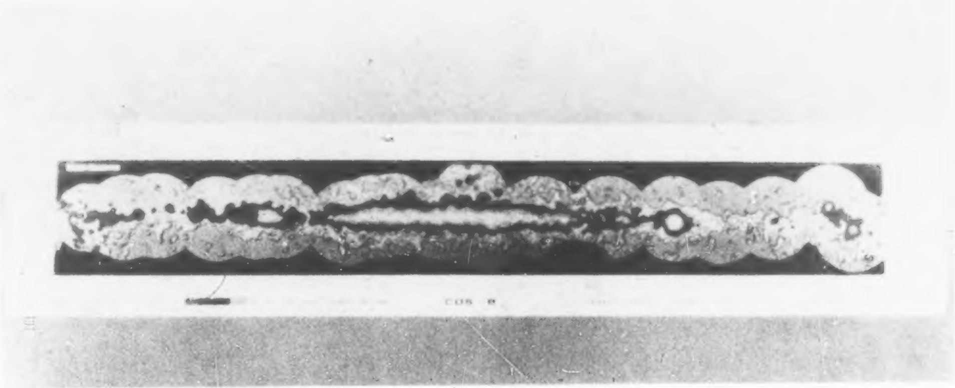


FIGURE 1.4. PICTURE OF THE SKY IN GAMMA RAYS

Gamma rays, with wavelengths of about 10^{-12} m, have extremely high energies and indicate areas in space where the most energetic events take place.

- Cosmic backgrounds and large-scale structure of the universe: What is the distribution of matter through the universe? What is the nature and origin of interstellar gas? How can we determine more accurately the distance and time scales of the universe? What are the origin, history, and fate of the universe? Where is the "hidden mass" that our calculations indicate should exist in the universe?

- Evolution of galaxies: How do galaxies form? How do they evolve? How can the different patterns of galaxies be explained? What kinds of activity occur in the nuclei of galaxies?

- Formation of stars and planets: What is the composition of molecular clouds in interstellar space? What role do molecular clouds play in star formation? What is the origin of interstellar dust? What are the origin, history, and fate of our solar system?

- Solar activity: What is happening on the Sun? How are mass and energy transported through the Sun and through space? What is the role of magnetic fields in energy production, storage, transport, and release?

- Forces of nature: Does gravitational radiation exist? How do electromagnetic and nuclear forces interact? Is a unified theory of cosmic processes possible?

The answers to most, if not all, of these questions require prolonged observation, full spectral coverage, higher sensitivity, and increased resolution (angular, spectral, and temporal). We want to look farther, longer, and in sharper focus for those revealing phenomena that will help us explain the cosmos. As we pursue our ambitious research program, we will be taking advantage of both maturing and emerging technologies to gain access to details of the universe that are fainter, more minute, more distant, and more mysterious.

Further Discoveries

We can make a convincing case that discovery keeps pace with technology. The imaginative application of new technology to reigning problems reveals previously inaccessible and unknown phenomena. Martin Harwit, in his intriguing study Cosmic Discovery, argues that there have been perhaps 43 major discoveries in the history of astronomy. Many of these discoveries resulted from new technology applications that enabled astronomers to scrutinize the heavens with greater clarity and precision. With the rapid development of instruments and techniques for astrophysics, we can expect a concurrent burst of discoveries in all parts of the spectrum.

If Harwit is correct about the finite number of significant kinds of objects in the universe and the relatively few discovered thus far, then we may, with new technology, equal or exceed the number of all previous discoveries. The rest of the universe may well be within the scope of observation during our generation. The challenge to astrophysics is to use new technology.to make the remaining discoveries. We expect the Space Station to figure prominently in our efforts to meet this challenge.

Thus, many believe that we live in a unique era. It is arguable that the next few decades will reveal the nature and scope of the universe to our generation. Our space observatories are the exploring "ships" of the 20th and 21st centuries as the vessels of the early explorers were to Spain and Portugal in the 15th century. To carry out the exploration of the universe under American leadership is to continue our national spirit--the technological and scientific advances will help sustain our technological excellence.

ASTROPHYSICS AND THE SPACE STATION

Since no field of science has ever benefited so dramatically from new technologies as space astrophysics, it is very important to observe that the Space Station is a grand technical advance that will bring a tremendous leap forward in our capabilities for astrophysics research.

The impact of the Space Station and its technology on the NASA Astrophysics program can be seen in Table 1, which maps the scientific requirements from each discipline into the key capabilities for accomplishing the investigation. Check marks indicate the current plan, while x's show capabilities needed in the more distant future. In every case, we have deleted reference to capabilities that could be used in principle but which did not make sound, fundamental sense. In the following sections, we discuss each of these capabilities.

The Space Station as an Observatory

To answer many of the open questions in astrophysics today, we need long observation periods, large instruments, and evolutionary instrument complements. The permanent Space Station certainly can serve as a platform for long-term investigations. Unlike an unmanned scientific satellite, the Space Station will be inhabited by crews of scientists and technicians who can operate, maintain, and use instruments for years of productive observation. Furthermore, the Space Station will be capable of bearing much larger instruments than a spacecraft can carry in orbit, and it can accommodate large, growing sets of instruments.

At present, it appears that the disciplines of solar physics and cosmic ray physics can best take advantage of this attribute of the Space Station to achieve our near-term scientific objectives. Because solar physics

SPACE STATION UTILIZATION
ASTROPHYSICS

	MANNED BASE			PLATFORMS			
	OBSERV. PLATFORM	SERVICE BASE	ASSEMBLY BASE	EXPLORER CLASS		OBSERV. CLASS	
				L	P	L	P
SOLAR							
INTERIOR (EXPL.)		✓			✓		
SURFACE (SOT/ASO)	✓	✓					
ATMOS (POF/ASO)	✓	✓					
ATMOS (POF/ASO)		✓		✓			
STARPROBE			X				
HIGH ENERGY							
X-RAY (AXAF)		✓				✓	
X-RAY(EXPL.)		✓		✓			
X-RAY (HTM)		✓	X			X	
G-RAY (GRO)		✓				✓	
G-RAY (EXPL.)		✓		✓			
COS RAY (CRNE & TRIC)	✓	✓					
COS RAY (HEIE)					X		X
COS RAY (HESSA)	X	X	X				
ASTRONOMY							
RADIO (OVLBI)		✓	X		✓	X	
SUB-MM (LDR)		✓	✓			✓	
IR (SIRTF)		✓				✓	✓
UV/VIS (ST)		✓				✓	
UV/VIS (STARLAB)		✓				X	
UV/EUV (FUSE)		✓		✓			
INTERFEROMETERS		X	X			X	
RELATIVITY							
GRAVITY WAVES		X	X				
GRAVITY PROBE-B							✓

✓ = CURRENT
X = FUTURE

L = LOW INCLINATION SERVICED BY SPACE STATION
P = POLAR INCLINATION SERVICED BY SHUTTLE

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instruments require stable pointing on short time-scales and, due to their warm surfaces, are less susceptible to contamination than other kinds of detectors, they are well suited to be attached payloads on the Space Station. Furthermore, as the Skylab experience demonstrated, solar physics investigations benefit from the quick-response capability of a manned mission when targets of opportunity and unforeseen events occur. Cosmic ray instruments, which chiefly require a clear view of space, also will benefit from the stable mounting and load-carrying capability of the Space Station. There it will be possible to mount very large instruments, with modest pointing demands, for long observing periods.

The Advanced Solar Observatory (ASO), starting with the Pinhole/Occulter Facility (P/OF) and the High Resolution Cluster of telescopes built around the Solar Optical Telescope (SOT), will be the major observatory for solar physics in the 1990's. While SOT will observe infrared, visible, and ultraviolet emissions from the Sun, P/OF will provide very high angular resolution for hard x-ray imaging of flares and allow investigations of the transport of heat into the corona at its base. Because these instruments are designed to be operated initially as part of the Spacelab program on the Shuttle, we expect that they can be accommodated on the Space Station without major technical problems. If anything, the Space Station should be more stable and have less contamination than the Shuttle, and the Station will enable the evolution of solar instruments as the ASO matures.

Cosmic ray instruments are well suited to the manned base because they have very low demands for pointing, power, and telemetry. Internally, these instruments must be complex so they can measure the charge and energy of relativistic nuclei to determine where they originated and how they achieved their extreme energies. However, all they require from the Space Station is a clear view of space over a wide field of view (30 to 60 degrees). The power demands (never more than 500 Watts) and data rates (less than 100 kbits/sec) are modest compared to the capabilities of the manned base. Like the ASO instruments, the cosmic ray experiments will be developed through the Spacelab program and will make their first exploratory observations from the Shuttle.

One key lesson we have learned from experimental programs such as Spacelab that used the Space Shuttle as an observation platform is that small experiments fill a vital role. We are beginning to implement low-cost experimental programs, such as Spartan and Hitchhiker, for the Space Shuttle. These programs have three objectives:

(1) Instrument testing and development. Low-cost, simple ways to gain frequent access to space are essential to develop the advanced instrumentation for tomorrow's major mission.

(2) Training and education. Activities have time scales which are far too lengthy to involve graduate students. Low-cost, simple space experiments provide the means to educate the coming generation of space scientists.

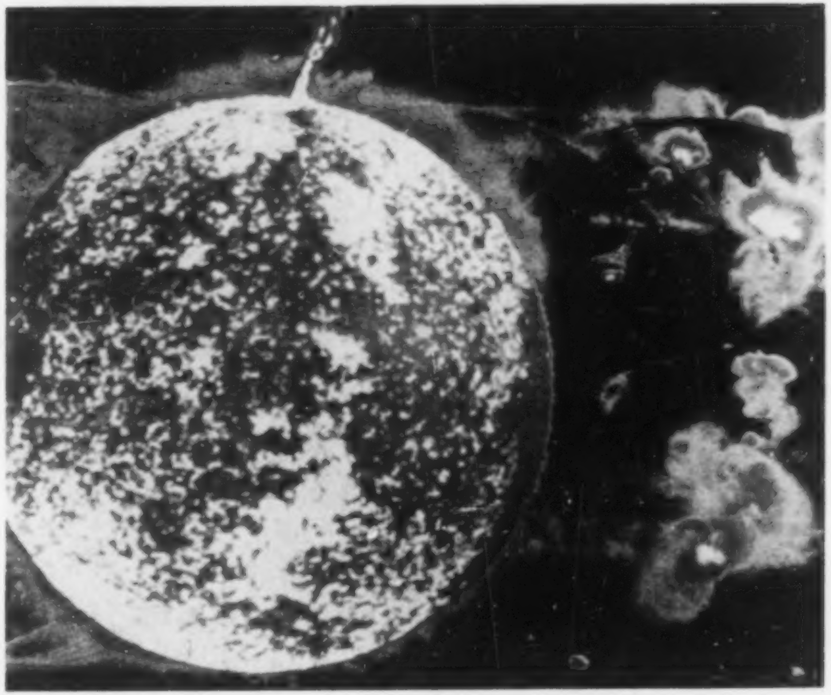


FIGURE 1.5. IMAGE OF THE SUN IN ULTRAVIOLET LIGHT

Images are dispersed by ultraviolet wavelengths in this picture taken on Skylab. Sharp images occur where there is strong ultraviolet emission at a specific wavelength.

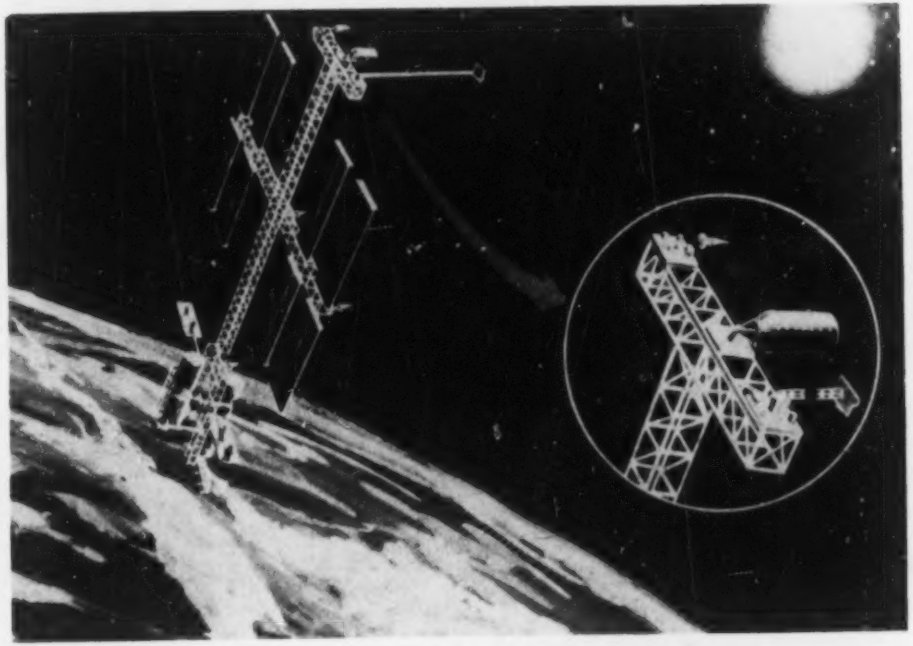


FIGURE 1.6. THE ADVANCED SOLAR OBSERVATORY

This major observatory for solar physics will observe the Sun in wavelengths from very low radio waves through nuclear gamma rays.

(3) Science. There are many specialized measurements which generate science results of the first rank. These opportunities, when provided frequently (and hence at low cost), ensure that scientists of the highest quality remain in space research between the larger mission opportunities.

As we embark on the Space Station project, it is vital that frequent access to space is retained for simple experiments. Many astrophysics experiments can make do with the pointing provided by the Shuttle attitude control system, but most astrophysics experiments require fine pointing (~1 sec). To provide fine pointing for simple experiments from the Shuttle or the Space Station implies technical and operational complexity which is inconsistent with the goals of low cost and simplicity.

The Spartan concept removes this complexity for simple instruments needing fine pointing (see Volume 5), and we should reserve small attached payloads for experiments with minimal pointing constraints. Our current estimates are that about 15 flight opportunities per year would be appropriate for Spartan experiment and up to five per year for Hitchhiker class (non-fine-pointed) experiments.

It is essential to include these kinds of experiments in the Space Station era. We strongly recommend that the Space Station program incorporate these capabilities using a combination of attachment ports on the manned base and use of subsatellites.

The ASO, the cosmic-ray experiments, and the opportunities for small attached payloads are described in Volume 2 of this report.

Satellite Servicing at the Space Station

One new technology that is crucial to the success of our research program is spacecraft servicing. The Solar Maximum Repair Mission, which restored the operation of a malfunctioning observatory, dramatically demonstrated the importance of servicing as an insurance policy against miscellaneous hardware failures. There are strong scientific and economic reasons for developing the servicing capability as an integral function of the Space Station. For astrophysics, long-lived observatories are necessary. If we intend to peer to the edge of the universe, we need enough time to find the interesting objects and investigate their physical condition. We cannot afford to lose our observatories because of hardware failures, empty fuel tanks, run-down batteries, or depleted cryogens; nor can we necessarily afford to send the Shuttle up on a service call every time something goes wrong. Instead, it makes sense for the Space Station to include an orbital service center equipped with tools, spare parts, and trained personnel prepared to repair failures, resupply consumables, and perform preventive maintenance to ensure long observatory lifetimes.

This servicing capability will be beneficial, in varying degrees, to each kind of astrophysics mission--attached payloads on the Space Station

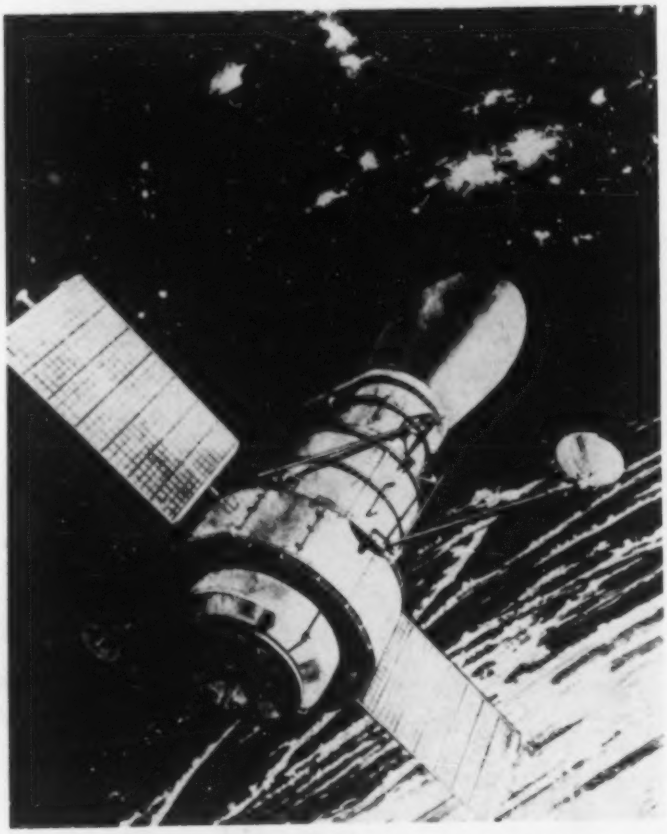


FIGURE 1.7. THE SPACE INFRARED TELESCOPE FACILITY

This cryogenically-cooled observatory will be the major observatory for infrared astronomy.

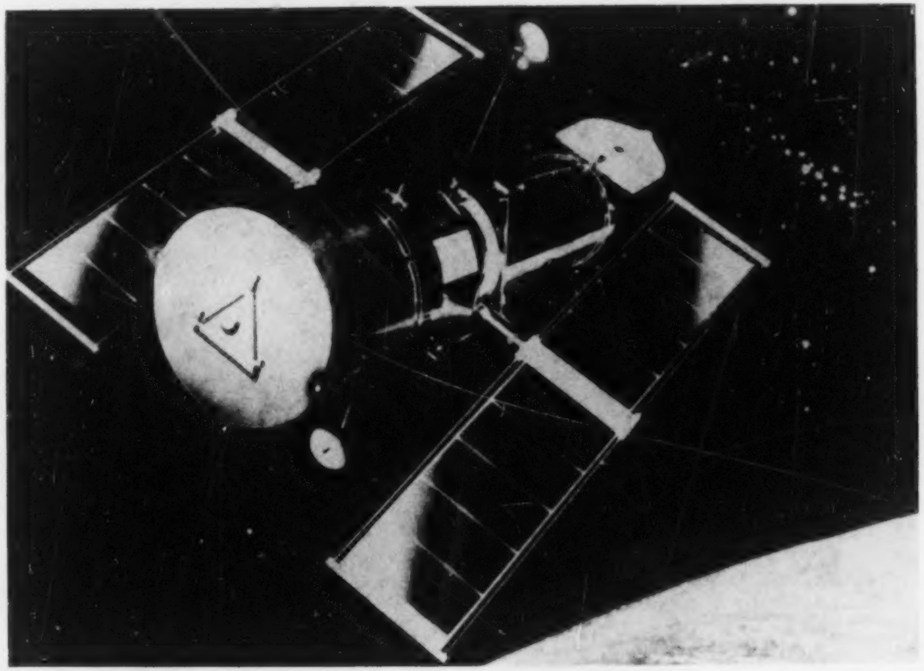


FIGURE 1.8. THE HUBBLE SPACE TELESCOPE

This major observatory for visible and ultraviolet light will begin operations in space in 1986.

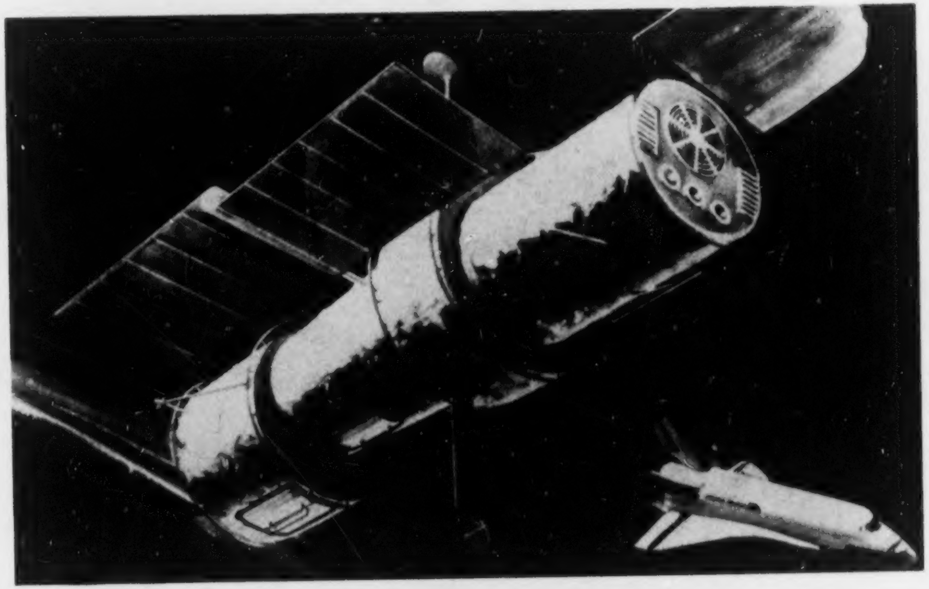


FIGURE 1.9. THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF).

AXAF will be as significant an advance in x-ray astronomy as the Hubble Space Telescope is for visible and ultraviolet astronomy. Launch of AXAF is planned for the early 1990's.

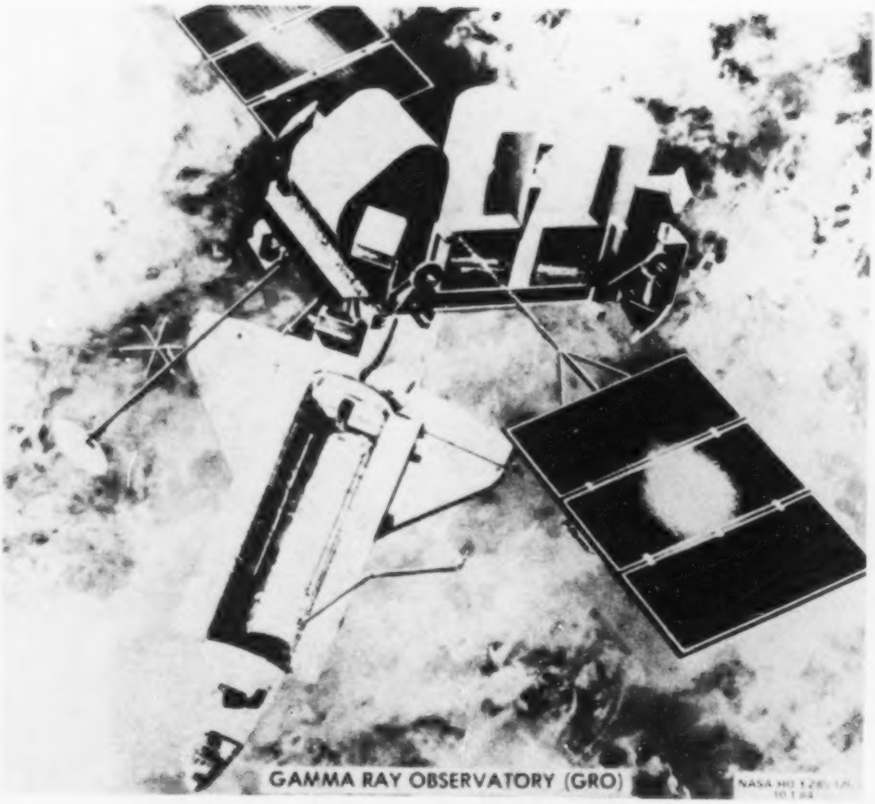

GAMMA RAY OBSERVATORY (GRO)

FIGURE 1.10. THE GAMMA-RAY OBSERVATORY

This is the first mission capable of observing the entire gamma-ray spectrum. It will be launched in 1988.

itself, co-orbiting free-flyers, and our major observatories, such as the Hubble Space Telescope, the Advanced X-Ray Astrophysics Facility, the Gamma Ray Observatory, and the Space Infrared Telescope Facility. Just as observatories on the ground are routinely maintained, so our observatories in space will require regular inspection, cleaning, repairs, resupply, and upgrading. Since they will be in compatible orbits, it will be more convenient to maintain these observatories from the Space Station than from the Shuttle, and it will be less costly to service them in space than on the ground. For optimal use, our sophisticated observatories should be kept operational without extensive interruption; they are our capital assets in space.

In addition, the Space Station will play an important role in upgrading instrumentation in orbit to take advantage of new advances in technology. New detector technology is crucial to astrophysics research, for it enables us to increase the capabilities of new and existing telescopes. The instruments of the Space Station era will be of a sensitivity many orders of magnitude better than we thought possible just a few years ago. During the next few years, we expect many improvements in charge-coupled device array detectors, cryogenic devices, radio receivers, cosmic-ray and gamma-ray detectors, spectrometers, and coating materials.

If instruments are designed for replacement and are accessible, members of the Space Station crew will be able to remove obsolete items and introduce state-of-the-art components. Upgrading scientific instruments in space, particularly by introducing new technology in the focal plane, will be a profoundly beneficial function of the Space Station for astrophysics.

As noted earlier, discovery keeps pace with advances in technology. Every missed opportunity to apply new technology to astrophysics research means a loss of potential knowledge. As a base for upgrading our instruments in orbit, the Space Station will save valuable time in maintaining state-of-the-art capabilities.

Volume 3 describes the servicing of astrophysics missions at the Space Station.

Assembling Astrophysics Missions at the Space Station

Another promising technology for astrophysics research enables us to build, in space, systems and devices significantly larger than can be carried into orbit by rockets or the Shuttle. The keys to progress in astrophysics are improved resolution and increased sensitivity. For some parts of the spectrum, this is achieved by using larger detectors spread over a greater area. For example, large instruments in space are necessary for spectroscopic and imaging observations in the far-infrared and submillimeter regions of the spectrum; to collect enough photons for analysis and to gain high angular resolution at long wavelengths, the proposed Large Deployable Reflector (LDR) is 20 meters in diameter.

The Space Station will play an important role as an assembly base for constructing and deploying large detector arrays. Parts will be delivered on multiple visits by the Shuttle and stored in readiness on the Space Station. There, an EVA construction crew, aided by the Remote Manipulator System, will be able to assemble and deploy large systems. Orbital construction activities will be a combination of automated deployment, human-operated robotics, and human assembly. Volume 4 first describes the scientific problems requiring large instruments, then some mission concepts, and finally some general technical requirements indicating the services that will be necessary for assembly late in the Space Station's lifetime.

Space Platforms for Astrophysics

The Space Station, with its servicing capabilities and its permanent presence, makes possible new concepts for spacecraft in both the observatory and Explorer classes. The long-lived astrophysical observatories that are developed to use the capabilities will also have the benefit of the technology developed for the permanence of the Station itself. The generation of spacecraft incorporating Space Station compatible technology and supporting these observatories has been called Astroplatforms to distinguish them from the generation that are based on Shuttle capabilities and technology. The Station generation starts with the Advanced X-ray Astrophysics Facility and the Space Infrared Telescope Facility.

Just as the major observatories are capital investments, so it will be possible for private business to invest in platform services in space. The Station makes it possible to change payloads every two or three years, and we are planning to use this new service as we implement our Explorer program.

Explorer missions for astrophysics are small instruments for specialized tasks. Two examples are the X-ray Timing Explorer (XTE), which is designed for long-term observations of a few bright X-ray sources, and the Far Ultraviolet Spectroscopy Explorer (FUSE), which will obtain spectra of very highly ionized interstellar and circumstellar gas.

Experience has shown that reducing the number of interfaces between unrelated activities is essential to keep system engineering from smothering in its own complexity. This is what leads us to continue with independent platforms that are the appropriate size for the facilities they are carrying. Besides observatories and Explorers, there will continue to be some payloads that can be handled by very small platforms that we call Space Station Spartans. These will carry small telescopes and provide spacecraft services for missions lasting from 1 to 3 months necessary for special investigations with new generations of instruments. These new instruments are the basis of all our future programs, and these small spacecraft will provide the opportunity for the new instruments to be fully tested in space before they are placed in our observatories.

In Volume 5, Observatory, Explorer, and Spartan mission for the Space Station generation are discussed. When these missions are under way, the Station will become the hub of space transportation where payloads can be exchanged and stored, freeing the Space Shuttle and various existing platforms to follow independent schedules.

REQUIRED SPACE STATION ATTRIBUTES FOR ASTROPHYSICS APPLICATIONS

As we seek ways to gain the best value for our investment in space, it is only prudent to consider what science we can do well from the Space Station and what accommodations the Space Station could provide to best meet our needs. It is clear that the Space Station figures prominently as an observatory base, service center, assembly site, and support node for a variety of missions. It is also clear that, for optimal utilization by astrophysicists, the Space Station must provide certain accommodations and services. Most of these accommodations, however, are necessary for many other uses of the Space Station and are not unique to the accommodation of astrophysics missions.

Desirable functional and architectural attributes are presented in each volume of this document. Some of the provisions deemed necessary on the Space Station are described below:

Observatory Needs

- Pointing and Stabilization
    - Fairly modest requirements for an unobstructed view of the Sun (solar physics) and space (cosmic ray physics); no specific attitude requirements
    - Isolation from vibration inputs above the capabilities of the Instrument Pointing System
- Low-Contamination Environment
    - Possible requirement for location away from Shuttle docking area
- Time
    - Uninterrupted duty cycle for solar instruments during sunlit portions of the orbit
- Command and Data
    - On-board processing and control capability for ASO

- Versatile capability to handle extremely low (100 kbits, cosmic ray investigations) to extremely high (100 Mbits, Solar Optical Telescope) rates.

Servicing Needs

- Service Center
  - Dedicated work area designed and equipped for a variety of maintenance and repair activities
  - Improved grapple and holding devices for spacecraft capture
  - Berthing platform and temporary storage bay
  - Remote Manipulator System/Robotics
  - Manned Maneuvering Unit
  - Orbital Maneuvering Vehicle
  - Logistics base - inventory of spare parts, tools, consumables
  - Support equipment for extravehicular activity
  - Advanced Extravehicular Mobility Unit
  - Airlock and "shirtsleeve" environment.

Assembly Needs

- Assembly Base
  - Construction site with provision to accommodate growing size and weight capacity
  - Standard tools
  - Advanced Remote Manipulator System, larger and more dextrous than the Shuttle RMS
  - Robotic assembly machines.

Support Needs

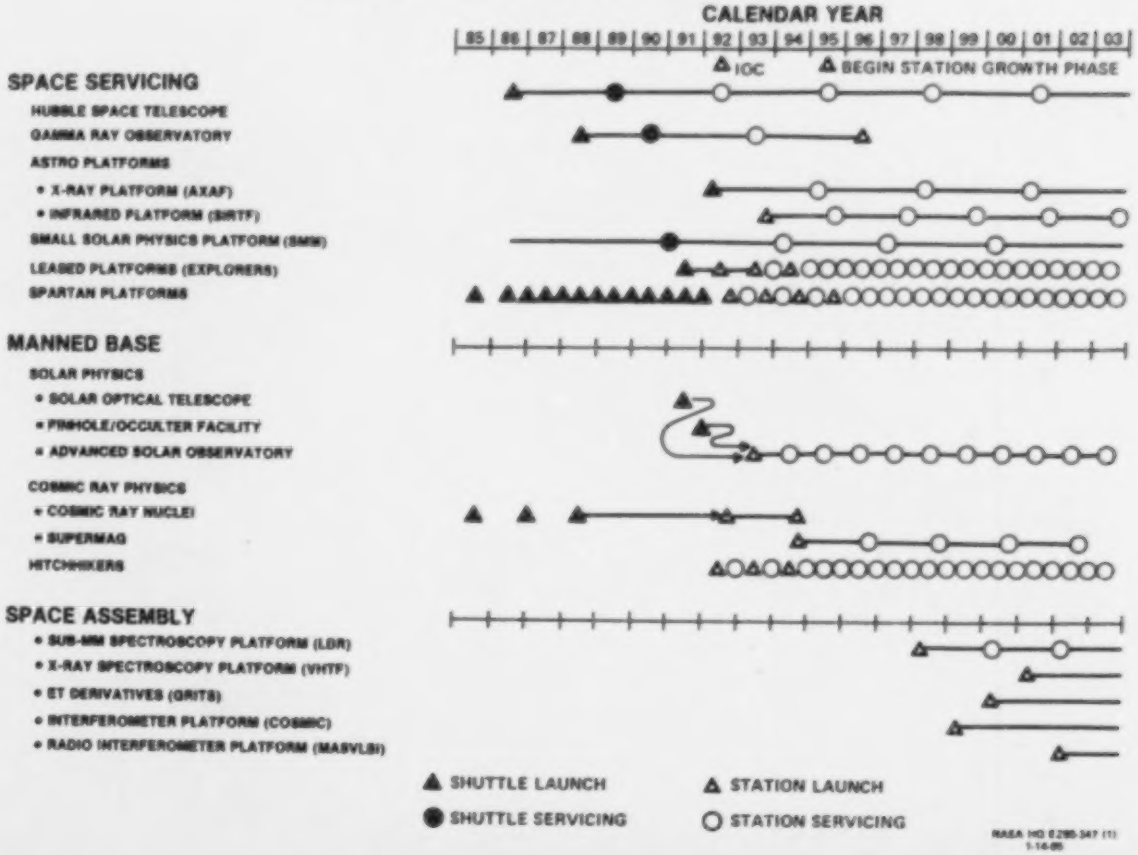
- Platform Support Node

- Requirements and interfaces comparable to those for service center.

If the Space Station can meet these requirements, astrophysics research will be able to benefit from the Space Station's capabilities. Through servicing, we will be able to maintain our orbital observatories and extend the lifetime of our missions. Through on-orbit assembly, we will be able to construct very large instrument systems. We can also mount large instruments and evolutionary complements of instruments on the Space Station, and we can support a fleet of small free-flyers. Table 2 shows when we plan each major use of the Space Station.

The Space Station represents the next leap in our use of space as a worksite. There we will be able to do and build and see and discover things that are impossible on the ground. It is the purpose of this document to help focus our talents and imaginations on the challenge of defining astrophysics requirements for this very important new resource.

ASTROPHYSICS/SPACE STATION



MEMBERS OF THE PANELS
WORKSHOP ON
ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Participants Making Special Contributions and Presentations

Dr. Charles J. Pellerin, Jr., Chairman
Mr. Philip E. Culbertson
Dr. David A. Gilman
Dr. Stephen S. Holt
Dr. Franklin D. Martin
Dr. George F. Pieper

Space Station as a Manned Observation Base

Dr. J. David Bohlin, Chairman
Mr. Jack Barengoltz
Dr. Robert C. Golden
Dr. Hugh S. Hudson
Dr. Stuart D. Jordan
Dr. Joseph Klarman
Mr. James Marr
Mr. Edward Mettler
Dr. Ronald Moore
Mr. Robert G. Noblitt
Dr. Jonathan F. Ormes
Ms. Amelia Phillips
Mr. William Roberts
Dr. Richard A. Shine
Dr. Daniel S. Spicer
Dr. Arthur B. C. Walker, Jr.
Dr. George L. Withbroe

Servicing Astrophysics Missions at the Space Station

Mr. B. Ronald McCullar, Chairman
Mr. Michael Bay
Mr. Richard Cable
Mr. Frank Cepollina
Dr. John Dickey
Mr. Ronald R. Felice
Ms. Jean C. Folse
Mr. Kevin J. Grady
Mr. Joseph P. Loftus, Jr.
Mr. Francis J. Logan
Mr. David R. Manges
Dr. Stephen P. Maran
Mr. James Murphy
Dr. Stephen S. Murray
Dr. Valerie Neal
Mr. Ed Pruett
Dr. Philip Schwartz
Dr. David R. Soderblom
Mr. Lewis Sprott
Mr. James Steincamp
Dr. David E. Thompson
Mr. Howard F. Trucks

Astrophysics Missions from Space Platforms

Dr. Louis J. Kaluzienski, Chairman
Dr. Paul A. Blanchard
Dr. Roger D. Bourke
Dr. Jesse D. Bregman
Dr. Alan N. Bunner
Dr. Webster Cash
Mr. Harry D. Cyphers
Dr. Sara Heap
Mr. William D. Hibbard
Mr. Peter Jasper
Dr. Knox S. Long
Dr. Richard A. McCray
Dr. Enrico Mercanti
Dr. Robert Novick
Dr. Stephen J. Paddack
Dr. Thomas A. Prince
Mr. Joseph Purcell
Dr. Robert Stachnik
Dr. Robert E. Stencel
Mr. David H. Suddeth
Dr. Jean H. Swank
Dr. Bonnard J. Teegarden

Assembly of Astrophysics Missions at the Space Station

Mr. Michael Kiya, Chairman
Mr. Paul A. Cooper
Mr. Thomas M. Crabb
Mr. Maurice Dubin
Mr. Kenneth Frost
Dr. Daniel Gezari
Mr. James Grady
Dr. Herbert Gursky
Mr. Peter Jones
Mr. Max Nein
Mr. R. Bruce Pittman
Mr. Fred Shepphird
Dr. Kandy Shivanandan
Mr. Thomas Sisk
Mr. Gene E. Stone
Dr. Robert Streitmatter
Dr. Paul N. Swanson
Dr. Wesley A. Traub
Mr. Alan B. Wissinger

Other Attendees

Mr. Gerald L. Burdett
Dr. Steve Dwornik
Mr. Arthur Fuchs
Dr. Richard E. Hartle
Mr. Theodor Kostiuk
Dr. Robert J. Krauss
Mr. Martin Ledston
Mr. William Morris
Mr. John F. Osantowski
Mr. Richard A. Reeves
Mr. David Roalstad
Mr. Sherm Schrock
Mr. Mark Sistilli
Mr. Edward C. Sittler, Jr.
Dr. William Smith
Dr. Sabatino Sofia
Dr. Donna E. Weistrop

ASTROPHYSICS AND THE SPACE STATION

VOLUME 2

THE SPACE STATION AS AN OBSERVATORY

Intrinsic to the concept of an American Space Station is a spacecraft rich in resources of power, telemetry, structural control, and permanent access to space. It is this richness that makes the Space Station the ideal vehicle for the primary scientific missions of Solar Physics and Cosmic Ray Physics. This volume describes our plan to use the Space Station to grasp the fundamental physics of the Sun with the Advanced Solar Observatory (ASO) and to observe rare but extremely significant components of the cosmic rays with a series of four cosmic-ray experiments.

This volume contains the results of the Panel on the Manned Base as an Observation Platform of the Workshop on Astrophysics Utilization of the Space Station. The panel was composed of solar physicists, cosmic ray physicists, program engineers, and program managers. Its conclusions are developed in three main sections: The Advanced Solar Observatory, Cosmic Ray Experiments, and Technical Requirements. At the very end of the report is a short section on small, attached experiments of opportunity that should be accommodated by the Space Station.

THE ADVANCED SOLAR OBSERVATORY (ASO)

Major Observatory for Solar Physics

The National Academy of Sciences, in its report Astronomy and Astrophysics for the 1980's, recommended the Advanced Solar Observatory as the most important new mission in Solar Physics. Starting with the Solar Optical Telescope and the Pinhole/Occulter Facility, the observatory will be built up from facilities flown on Spacelab, and when the full complement is in place on the Station, we will have an observatory capable of answering the most important and fundamental questions we have about the Sun.

The ASO will be able to overcome the two major limitations of Earth-based observatories. The first limitation is that the Earth's atmosphere allows only that small fraction of the electromagnetic spectrum which we call visible light to reach ground-based telescopes; therefore, many phenomena, especially those of a highly energetic nature, cannot be properly observed because they emit mainly in ultraviolet, extreme ultraviolet, x-ray, or

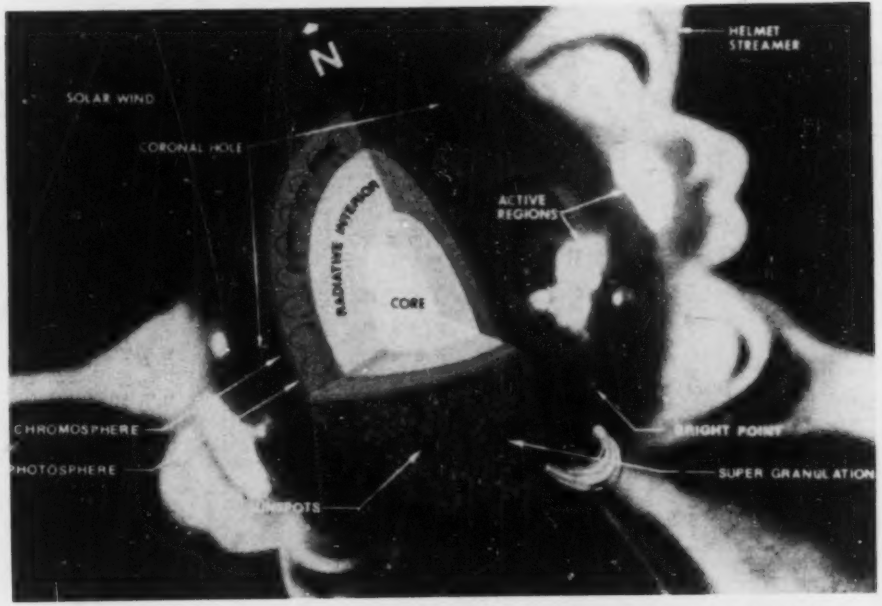

N
SOLAR WIND
CORONAL HOLE
RADIATIVE INTERIOR
CORE
ACTIVE REGIONS
HELMET STREAMER
CHROMOSPHERE
HOTOSPHERE
SUNSPOTS
BRIGHT POINT
SUPER GRANULATION

FIGURE 2.1. THE SUN, SHOWING THE MAJOR HELIOGRAPHIC DOMAINS

Heat from nuclear fusion in the core diffuses through the radiative interior and drives the boiling motion of the convection zone. The surface, or photosphere, is at the top of the convection zone, and the boiling can be seen in the network of cells called supergranulation. Convection must also cause--although we do not know how--the strong magnetic regions that occur in sunspots, bright points, active regions, and the structure of the corona. The atmosphere of the Sun consists of a visible inner corona and an invisible outer corona that includes the solar wind. Between the surface and the inner corona lies the chromosphere, which is rich in visible, spectroscopic information.

gamma-ray wavelengths that are completely absorbed by Earth's atmosphere. Second, turbulence in the Earth's atmosphere creates an effect known as "seeing" which distorts and smears the smallest features of the Sun's atmosphere and prevents sustained study by diagnostic instruments. Thus, the solar astronomer faces a somewhat ironic situation: although the closeness of the Sun provides copious energy for observation with telescopes and detectors of modest size and sensitivity, nearly all major breakthroughs in modern solar physics are likely to be accomplished only by, or in association with, observations from space.

ASO Suited to Space Station

The Space Station Manned Base is an attractive home for the Advanced Solar Observatory especially because the Station allows ASO to grow from the initial facilities into the major observatory for the Sun covering all wavelengths. The Space Station is unique in having a permanent, manned presence for operations, upgrading instruments, repairing facilities, and replacing consumables. The Skylab experience demonstrated the strong need for close manned monitoring and control of solar telescopes to select the best target areas on the Sun and for quick reaction to capture targets of opportunity. Because of this lesson, solar scientist astronauts (Payload Specialists) will be aboard Spacelab 2 to operate its cluster of solar telescopes.

Because the major ASO instruments will be developed and flown on Spacelab missions prior to long-term deployment on the Space Station, they will be designed to cope with the Shuttle/Spacelab environment. We expect that the Space Station environment will be less severe than that of the Shuttle, particularly for contamination and pointing stability. Hence, the ASO instruments developed on Spacelab will have considerable built-in capability for functioning well on the Space Station.

Solar Physics: Fundamental to Astrophysics

Historically, the study of the Sun has proven to be a Rosetta stone for astrophysics. The Sun first told us that stars can develop strong magnetic fields and that magnetic activity occurs in regular cycles. It was on the Sun that we discovered layers of hot, partially ionized gas called chromospheres that are especially sensitive to the flow of matter and energy from stars, and we discovered atmospheres of fully ionized gas in coronae that are heated (by processes not yet identified) to temperatures more than 1000 times the temperatures of the stars they cover. We learned first from the Sun of cataclysmic releases of radiant and plasma energy and of both sustained and sporadic ejection of matter into interstellar space.

Solar Optical Telescope and High Resolution Telescope Cluster

The High Resolution Telescope Cluster (HRTC) is a group of telescopes that will permit detailed observations of the solar atmosphere over the entire range of temperatures from 5,000 to 10,000,000 K. The instruments in the HRTC, shown in Figure 2.2, include:

- The Solar Optical Telescope (SOT), a high-resolution telescope sensitive from the infrared, through visible and into vacuum ultraviolet wavelengths.
- The Soft X-Ray Telescope, sensitive to low energy ("soft") x-rays, which will allow detailed observations of the behavior of the Sun's corona (where the temperature is between 1 million and 5 million degrees).
- The EUV Telescope, sensitive to extreme ultraviolet (EUV) rays, which will obtain information about the chromosphere/corona transition region (where the temperature ranges from 500,000 to 10 million degrees).

These instruments can work either independently or together. When working together, they will be able to study the constantly changing phenomena that determine the structure and dynamics of the chromosphere and corona through the full range of temperatures now known to be involved in many solar phenomena.

The HRTC will also study the sudden release of energy and high energy particles that accompanies a solar flare. In a flare, both the buildup and the release of energy appear to depend critically on the fine structure of the solar magnetic field, which is reflected in the fine details observed at all temperatures in the solar atmosphere.

The first of these telescopes, the Solar Optical Telescope, is already being developed and will be used on Spacelab in the early 1990's. Because the Solar Optical Telescope will be used first, it is the only one that is discussed in detail in this volume. However, some of the instrumentation supporting the HRTC is also discussed, particularly the helioseismometer.

The Solar Optical Telescope

The most demanding of all the ASO facilities will also be the first one developed. The SOT will investigate the fundamental physics of the surface atmospheres of the Sun, as shown in Figure 2.3.

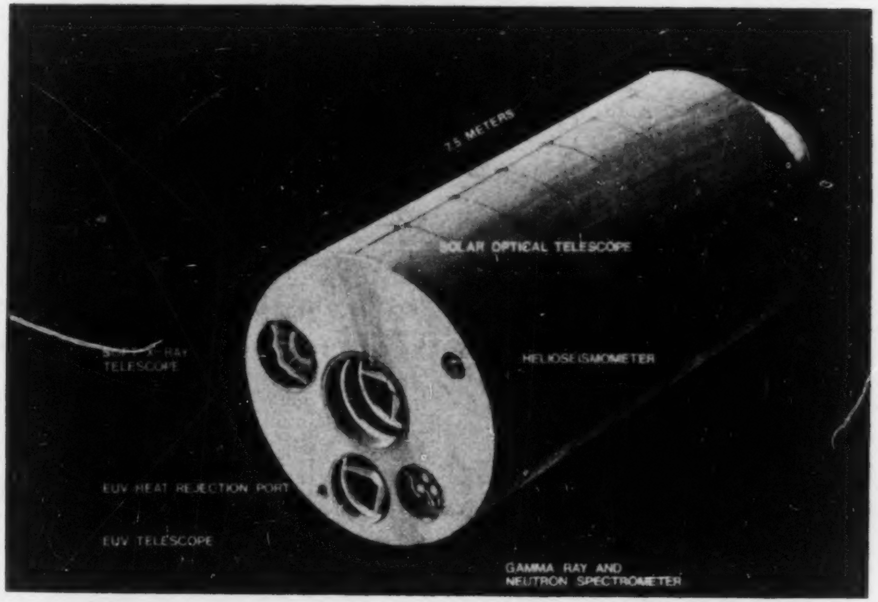

7.5 METERS
SOLAR OPTICAL TELESCOPE
HELIOSEISMOMETER
SOFT X-RAY TELESCOPE
EUV HEAT REJECTION PORT
EUV TELESCOPE
GAMMA RAY AND NEUTRON SPECTROMETER

FIGURE 2.2. THE SOLAR OPTICAL TELESCOPE AND THE HIGH RESOLUTION TELESCOPE CLUSTER

The primary high resolution instruments--the SOT, the Soft X-Ray Telescope Facility, and the Extreme Ultraviolet (EUV) Telescope Facility--are accompanied by wide-field instruments such as the Gamma Ray and Neutron Spectrometer and the Helioseismometer shown here. Other wide-field and high resolution instruments will be added during the ASO mission on the Space Station.

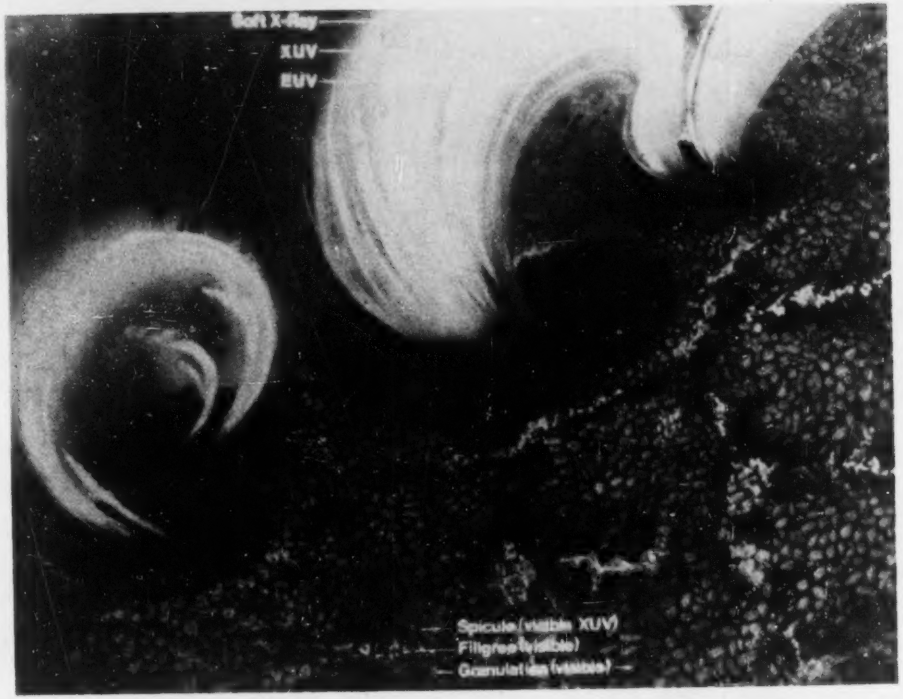

Soft X-Ray
XUV
EUV
Spicule (visible XUV)
Filigree (visible)
Granulation (visible)

FIGURE 2.3. FUNDAMENTAL PHYSICS OF THE SURFACE OF THE SUN

When we observe the Sun in visible light, the smallest structures we can resolve are granulation, spicules, and filigree. With the Solar Optical Telescope, we will be able to resolve much smaller structures--as little as 100 kilometers across. With this improved resolution, we expect a leap in understanding comparable to that which occurred when microscopes first resolved living cells.

The SOT is a 1.25-meter telescope achieving 0.1 arcsecond (about 100 kilometer) resolution over the ultraviolet, visible, and infrared spectrum from 1100 to 10,000 Angstroms. The optical configuration is Gregorian, in which the secondary mirror is concave and placed beyond the image formed by the primary mirror. This allows a reflective stop to be placed right at the primary focus to divert most of the light and heat away from the secondary mirror, except for the light from the relatively small area under study, which passes through a hole in this heat rejection mirror. The secondary and tertiary mirrors focus this light into the scientific instruments. With this optical system, and by careful control of contamination, the SOT's design should provide excellent performance in the vacuum ultraviolet.

The science instruments that will accompany the SOT on its first Spacelab mission include two film cameras, a visible light filtergraph-polarimeter, and visible and ultraviolet spectrometers.

The telescope housing also supports the focal plane instruments, and the entire ensemble is mounted on Spacelab's Instrument Pointing System. During the course of its development flights on the Space Shuttle, the SOT will carry the other HRTC instruments as well.

Helioseismometer

Current technology will not allow high resolution over the entire face of the Sun; high resolution instruments are necessarily limited to narrow fields of view. There are, however, important observations to be made over the Sun as a whole. These include wide field x-ray and extreme ultraviolet views of the Sun and its lower atmosphere. A gamma ray and neutron spectrometer will be included in the HRTC to study the acceleration of electrons and ions to very high energies, providing information about the Sun as a whole. But one of the most specialized instruments supporting the HRTC is the helioseismometer, which will be able to study the Sun's interior.

The helioseismometer is a modest-sized, 12-centimeter visible light telescope. However, it will perform what in some ways will be the most profound observations of the entire ASO: recording the subtle vibrations of the Sun to find out what is going on far below the visible surface.

The fact that the Sun's interior can be studied at all by observing its outer surface is a relatively new development in solar physics. The helioseismometer will measure oscillations on the Sun's surface and relate them to the Sun's internal structure, just as earthquakes are used to infer the subsurface structure of the Earth. The key to using this technique successfully is to measure the speed (meters, or even centimeters, per second) of small portions of the Sun's surface for a long time (weeks to months).

Such long periods of uninterrupted observation are only obtainable in space. The view from space can also reliably provide clues to the source of the Sun's magnetic field. This fact makes the helioseismometer one of the most interesting of the instruments supporting the HRTC.

Pinhole/Occulter Facility

Although the Pinhole/Occulter Facility (P/OF) may be the second major facility developed for the ASO, it may be the first to fly on the Space Station, since its planned development schedule coincides with that of the Space Station.

While physically large, the P/OF is deceptively simple. Figure 2.4 shows the P/OF with its 50-meter boom separating the instruments from a combined occulting edge and pinhole mask. The occulting edge acts as an artificial moon to create an "eclipse" for instruments viewing the Sun's corona, while the pinhole mask lets x-rays from solar flares through its small holes onto an array of x-ray detectors. The extremely long boom is critical both for providing an optimum "eclipse" geometry as well as achieving high angular resolution of the x-ray imaging. Imaging through a pinhole is the simplest camera possible; by taking this approach, the P/OF is able to produce images with "hard" x-rays whose energies are too high to be reflected by grazing incidence telescopes such as the Soft X-Ray Telescope in the High-Resolution Telescope Cluster. The occulter of the P/OF produces a good reproduction of an eclipse so that instruments can observe the faint outer atmospheres of the Sun, its chromosphere and corona, without the overpowering glare from the disk.

The impetus for coronal observations with the P/OF comes from two major developments in the 1970's. First, the study of the Sun's inner corona without the benefit of a natural eclipse was vaulted into the space age by the successful operation of white light coronagraphs and soft x-ray telescopes on OSO-7 and Skylab in the mid-1970's (Figure 2.5). The second major advance, also in the middle 1970's, came with the finding that certain coronal emissions, first observed in a rocket-borne experiment during the solar eclipse of 1970, could directly measure the velocities and temperatures of ions in the coronal plasma.

As a result of these developments, once the P/OF is in space, we will be able to discover the fundamental plasma parameters--temperature, density, and velocity--entirely by remote optical techniques. Coronal white light will be used to measure the density of electrons, and coronal ultraviolet light will be used to measure the temperature of the electrons, the state of ionization for atoms heavier than hydrogen, and the velocity and temperature of hydrogen ions. Thus the P/OF will be able to tell us practically everything that we need to know in order to infer how the Sun's corona is heated to the point where it finally escapes as the solar wind.

The Advanced Solar Observatory and the Solar Terrestrial Observatory

When we learn about the physical nature of the Sun, we not only learn fundamental science but also obtain practical information that one day may allow us to predict conditions on Earth that are affected by conditions on

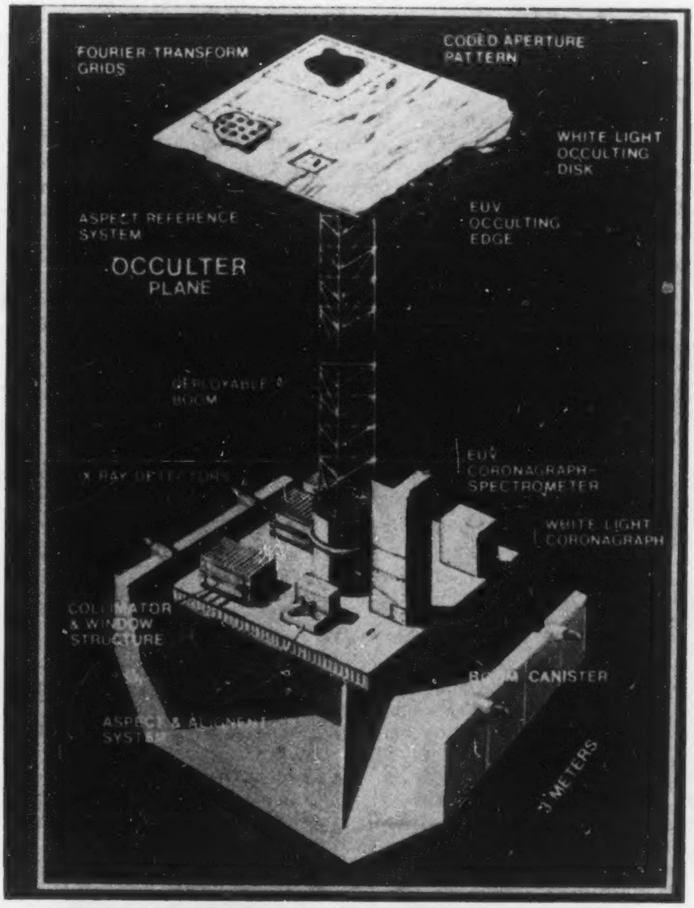

FOURIER TRANSFORM GRIDS
CODED APERTURE PATTERN
WHITE LIGHT OCCULTING DISK
ASPECT REFERENCE SYSTEM
EUV OCCULTING EDGE
OCCULTER PLANE
DEPLOYABLE BOOM
X-RAY DETECTORS
EUV CORONAGRAPH-SPECTROMETER
WHITE LIGHT CORONAGRAPH
COLLIMATOR & WINDOW STRUCTURE
BOOM CANISTER
ASPECT & ALIGNMENT SYSTEM
3 METERS

FIGURE 2.4. PINHOLE/OCCULTER FACILITY

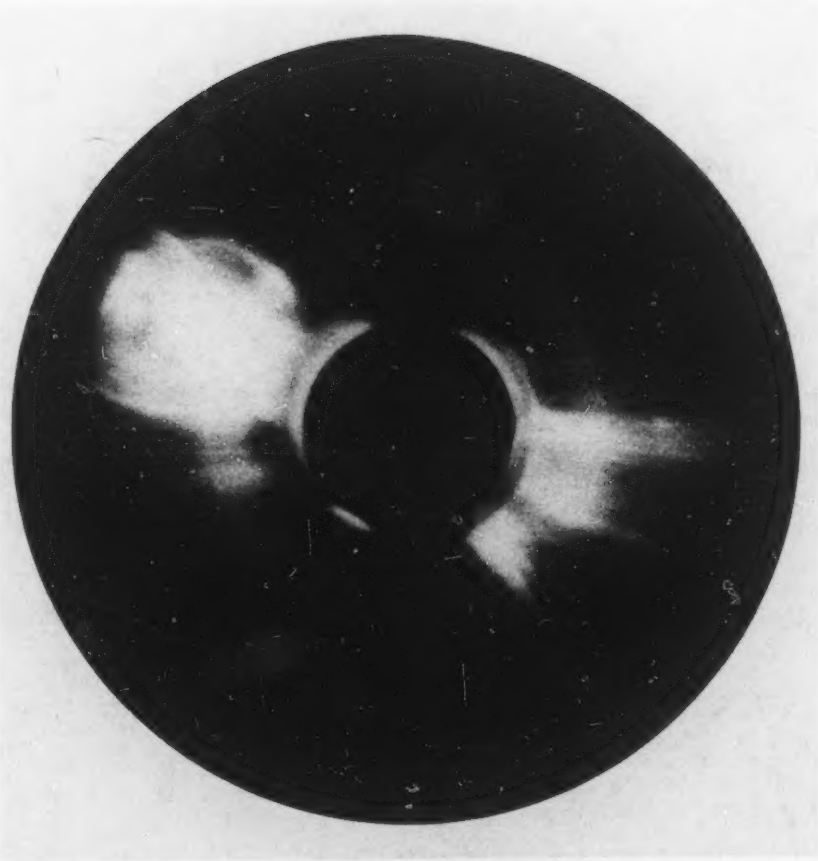


FIGURE 2.5. LARGE CORONAL EJECTION OBSERVED WITH THE CORONAGRAPH ON SKYLAB

The occulting disk covers twice the diameter of the Sun.

the Sun. The Sun's ultraviolet light, x-rays, and solar wind cause events in the earth's magnetosphere such as geomagnetic storms, short wave radio fadeout and aurorae. As technology in our lives becomes more sophisticated and more sensitive, we become increasingly affected by these phenomena.

One mission that has been proposed specifically to understand the possible effects of solar variability on the Earth's atmosphere is the Solar-Terrestrial Observatory (STO). An obvious criterion for a successful study of solar-terrestrial relationships is that of long term observations--ideally a full solar cycle of 11 years. The Space Station can be an essential base for such a program.

The STO, as currently envisioned, has four main groupings of instruments: the first will optically monitor solar activity and measure total luminosity and the irradiance in specific spectral bands; the second will measure the solar wind flux just outside the Earth's magnetosphere; the third will measure mass and energy transport through the magnetosphere and into the Earth's ionosphere; and the fourth will monitor by remote optical techniques the electric currents, photochemical processes, atmospheric turbidity, and other responses of the lower terrestrial atmosphere. Altogether, a fully implemented STO could involve 20 to 40 separate instruments.

The functions of some of the STO's solar instruments can be accomplished by those planned for the fully mature ASO on the Space Station. The solar wind measurements would, of course, have to be made in interplanetary space. The other two parts of the STO payload would be accomplished by a mix of in situ spacecraft and instruments located on the Space Station; in either case they would be available for periodic refurbishment and servicing using the capability of the Space Station.

COSMIC RAY EXPERIMENTS

Because of its resources in size, human access, and long duration in space, the Space Station is ideal for conducting cosmic ray experiments to observe the most energetic particles known to exist. These experiments will investigate the physics of particles traveling at very close to the speed of light, and they will reveal where cosmic rays come from, what it was like where they were accelerated, and what they traveled through to reach Earth. These are the fundamental problems of cosmic ray physics.

Unlike electromagnetic radiation, cosmic rays are charged particles. Most are the nuclei of normal atoms that have been stripped of their electrons and accelerated to more than 99 percent of the speed of light. Some carry more than 1 Joule of energy in a single proton. There are also electrons among the cosmic rays, and although electrons are less than 1 percent of the total, they are just as energetic.

The big question remains: How did the cosmic rays receive their enormous energies? In 1979, we were fairly certain that cosmic rays were accelerated in supernova explosions, and in that year, we launched the Third High Energy Astronomy Observatory (HEAO-3) to find the heavy cosmic ray nuclei like uranium that can only be created explosively. We expected to learn a lot about the nuclear events occurring at the onset of a supernova, but by the middle of 1980, it was already clear that the theory was wrong. Although supernova explosions may supply the energy to accelerate the cosmic rays, they do not do it directly, and they do not supply the particles themselves. We are still left with the big question.

The Space Station is a unique and ideal platform from which to answer that question. Because cosmic rays are charged, they generally must bend around magnetic field lines. However, at velocities very close to the speed of light, they can penetrate the Earth's magnetic field with little bending. In near-Earth orbit, the Space Station will carry instruments with wide fields of view, to maximize the number of particles that can observed. The Space Station also provides opportunities for long-term observations and the capability for in-space construction. These are necessary to obtain the collecting power required to study large numbers of these extremely energetic particles.

The following summarizes a plan for using the Space Station to support three major cosmic ray experiments: the Cosmic Ray Nuclei Experiment/Transition Radiation and Ionization Calorimeter (CRNE/TRIC) to determine what cosmic rays have traveled through to reach the Earth; the High Energy Space Station Array (HESS Array) to determine how the cosmic rays were accelerated and how atomic nuclei behave; and the Superconducting Magnetic Facility (SCMF) to determine why cosmic rays remain in our galaxy. A fourth experiment, the High-Energy Isotope Experiment (HEIE), is described here to show how the set of four experiments can work together to solve intertwined problems of the synthesis of cosmic ray nuclei, their acceleration, their transport through the gas of the interstellar medium, and their escape from the galaxy. Each of these experimental packages will evolve through the Spacelab or Shuttle-Attached-Payloads programs.

Cosmic Ray Nuclei Experiment/Transition Radiation and Ionization Calorimeter

The Transition Radiation and Ionization Calorimeter (TRIC) will be a reconfiguration of the Cosmic Ray Nuclei Experiment (CRNE) developed for Spacelab 2. In addition to the transition radiation detectors of the CRNE, the TRIC package will include an ionization calorimeter to measure the total energy of incoming cosmic rays. CRNE/TRIC will fit inside the pressurized shell shown in Figure 2.6 and will have essentially the same electrical and mechanical interfaces as the CRNE Spacelab experiment. After 2 years of operation on the Space Station, CRNE/TRIC will have measured the energies of protons and helium nuclei to energies up to a million GeV and the energies of rarer nuclei (up to zinc in the periodic table) with energies up to at least 1000 GeV and perhaps even to 10,000 GeV. We use the GeV (giga electron-volt) as a convenient unit of energy for cosmic rays; if all the mass in a proton or neutron were converted to energy, the energy, mc^2, would equal 0.94 GeV.

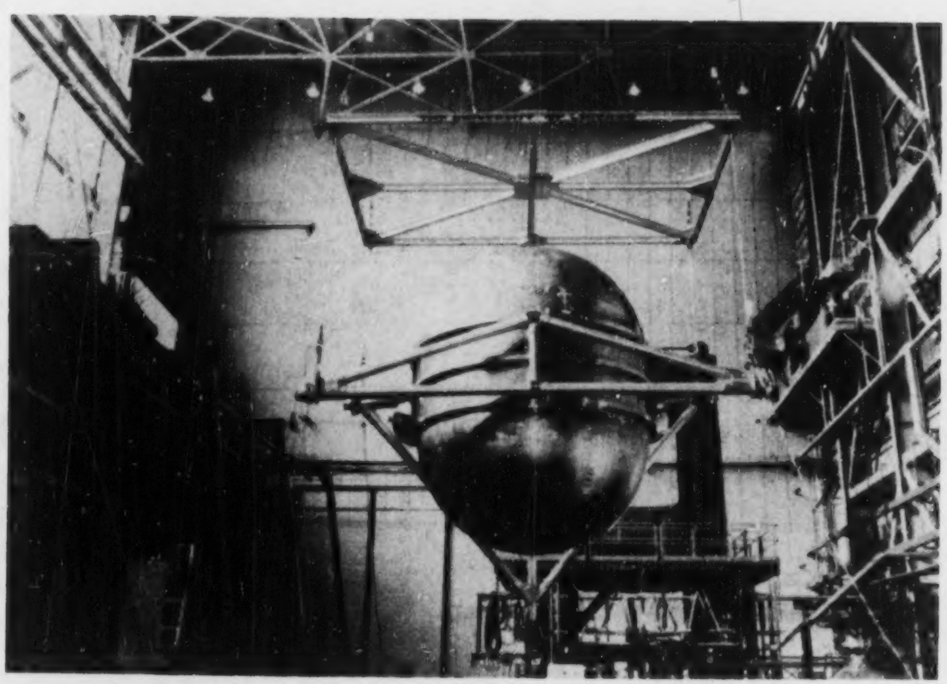


FIGURE 2.6. THE COSMIC RAY NUCLEI EXPERIMENT FOR SPACELAB 2

This experiment will operate from the Space Shuttle bay to investigate the composition of cosmic rays with energies between 20 GeV and 1000 GeV. Its complex interior design will be modified to create the Transition Radiation and Ionization Calorimeter experiment for the Space Station. The external design and the interfaces will not be changed.

Transport

Imagine what the Galaxy looks like to a cosmic ray. From the point of view of a primary cosmic ray--an oxygen nucleus, for example--traveling at a speed that differs from the speed of light by only one part in a million, the magnetic field of the Galaxy will appear as a rotating electric field that moves the nucleus in a circle as the Galaxy rushes by. Meanwhile, the stars and all the gas and dust between the stars appear to crowd together into a bunch racing directly toward the nucleus.

The stars are easy to miss; there are few of them. But the gas particles are there by the billions, each atom approaching at velocities not yet achieved in the most energetic particle accelerator on Earth. Within a few thousand years, from the point of view of the nucleus, either the Galaxy will pass by, or one of those extremely energetic atoms will strike it, blasting the nucleus backwards into a shower of nuclear fragments called secondary cosmic rays.

TRIC to Solve the Transport Problem

The problem is to separate the secondary cosmic rays from the primary ones. The primary composition will tell us the composition of the source of the cosmic rays, and analysis of the secondaries will tell us about the matter that the primaries have traveled through to reach the Earth. By being tuned to the highest energies that can yield a significant statistical sample, CRNE/TRIC will be ideal for analyzing the transport of cosmic rays and determining the composition at the source.

CRNE/TRIC can easily tell which of the cosmic rays it sees are the secondary nuclear fragments of more massive primary cosmic rays. Lithium is an example. Lithium is relatively plentiful among the cosmic rays (although hydrogen and helium are much more abundant), but it is extremely rare within the solar system. Clearly, the cosmic ray lithium comes from the collisions of abundant carbon, nitrogen, and oxygen cosmic rays with the gas between the stars.

Proof comes from the fact that lithium gets rarer at higher energies more quickly than the carbon, nitrogen, or oxygen from which it comes. In general, the energetic primaries that produce energetic secondaries suffer a greater shock than less energetic primaries when they collide with the interstellar gas. As a result, secondaries become much less important at higher energies.

This makes CRNE/TRIC ideal for distinguishing between primary and secondary contributions to cosmic rays where the distinction is not so clear as it is for lithium. At the highest energies, the primary cosmic ray contribution should dominate and provide an unambiguous measurement of the composition at the source.

Sample of Material from Beyond the Solar System

The solar system material was assembled out of interstellar gas and dust 4.6 billion years ago, while the cosmic ray material is only about 10 million years old--based on radioactive dating. Already, from HEAO-3 and balloon-borne cosmic ray experiments, we have discovered small but significant differences between solar system abundances and cosmic ray abundances.

The most provocative difference is an overall trend with a small excess of atoms that are easy to ionize and a slight deficiency of atoms that are hard to ionize. Acceleration cannot proceed while the atoms are electrically neutral, so this dependence on ionization threshold could be very significant. If cosmic rays are formed in explosive events, such as a supernova, then all atoms would be ionized no matter what their threshold. However, if the initial accelerations occurred in a more gentle, low-temperature region, the atoms would be selectively ionized. What we have seen suggests that the initial acceleration occurred in gas that was between 10,000 and 15,000 degrees--the temperature characteristic of gas surrounding young, hot stars.

Superconducting Magnet Facility

The Superconducting Magnet Facility (SCMF) will use a powerful superconducting magnet on the Space Station to investigate four significant aspects of the cosmic ray puzzle that cannot be observed any other way. Magnetic spectrometers are unique in their ability to determine the charge of a particle. This capability will allow us to look for antimatter--antiprotons, positrons, and heavier antinuclei such as antihelium.

The significance of antiprotons and positrons is that we know their rate of production, so SCMF will be able to teach us about the rate at which they are lost. SCMF will also resolve an enigma in low-energy antiprotons: the unexplained excess of low-energy antiprotons in cosmic rays. More profound would be the discovery of an antinucleus other than an antiproton. Antihelium, for example, could never be produced as a secondary particle from the collision of two normal nuclei; it can only appear in our detectors if it were a primary cosmic ray--that is, if it came from a region of space composed of antimatter stars and galaxies.

To deflect these particles, SCMF will need to produce a magnetic field that is more than a thousand times the strength of the Earth's magnetic field. Furthermore, this field must be nearly uniform over a wide area, about 1 square meter. Such a field is really only conceivable with electromagnets, and the only reasonable approach in space is to use a superconducting electromagnetic, which is made with wires that have exactly zero resistance when they are cooled to the temperature of liquid helium. Once a superconducting magnet is charged, no additional power is required to keep it going.

Besides giving support to the SCMF and a clear view of space, the Space Station is especially attractive because it provides a means of resupplying the liquid helium that keeps the magnet superconducting. This would be required every 6 to 12 months, depending on the design.

The presence of people on the Space Station will allow the SCMF to be rearranged to accommodate a wide variety of experiments. In addition to the antimatter searches, these include studies of cosmic ray isotopic composition, radioactive nuclei, accurate determination of elemental energy spectra, electron spectra, and possibly nuclear interaction studies with "tagged" heavy nuclei. When built, the SCMF will be the focus of cosmic ray studies through the end of the century.

High-Energy Isotope Experiment

HEIE is another important cosmic ray experiment that can be carried out with the volume, weight, power, and telemetry requirements of CRNE/TRIC. Unlike those missions, however, the HEIE will only gather useful data when it is at latitudes greater than about 45 degrees. Only there will the instrument have access to cosmic rays with energies low enough to measure their masses along with their charges and energies.

Ideally, we would like to know the mass of each cosmic ray that reaches any of our experiments--in addition to knowing the cosmic ray's charge and energy. Although a general description of a nucleus is contained in its charge (the number of protons it has), its specific nuclear history is often encoded in the number of neutrons it has. This is revealed by measuring the mass.

Observations made at high latitudes by balloon-borne experiments have found that cosmic-ray neon, magnesium, and silicon contain more neutron-rich isotopes than the same terrestrial elements, but this is very difficult to understand with our current theories of how nuclei are formed.

High-Energy Space Station Array

The High-Energy Space Station Array (HESS Array) is made possible by the technical capability provided by the Space Station to assemble large facilities in space. The Space Station will allow us to assemble the HESS Array and operate it for the 2 years necessary to find out how the acceleration of a cosmic ray depends on its composition at the highest energies.

Deployed in space, the HESS Array will be able to determine the compositions of cosmic rays that cause showers of particles in the Earth's atmosphere. This is a fundamental observation in cosmic-ray studies, and it affects a wide variety of Earth-based observations. The detector must be able to identify the charge and measure the energy of a cosmic ray with an energy of several million GeV; these cosmic rays are exceedingly rare, so the detector must be very large (about 4 meters on a side) just to observe enough cosmic rays in 2 years to tell how the composition of the showers changes with energy. Consequently, the HESS Array will be so massive that it cannot be carried up in a single Shuttle launch; it will have to be carried up in pieces and put together in orbit. This will be possible only with a manned Space Station.

In addition to providing information about the cosmic rays themselves, the HESS Array will provide physicists with a unique probe of the atomic nucleus. THe HESS Array will contain space for nuclear target and track-recording materials that will be removed every 3 months and sent back to the Earth for analysis. Investigators from around the world will provide target materials and analyze the exposed materials.

The cosmic rays will collide with the targets at a velocity so close to the speed of light that the collision products should be solely the result of strong nuclear interactions, the most enigmatic forces known to science.

TECHNICAL REQUIREMENTS

This following discussion outlines technical requirements for accommodating the Advanced Solar Observatory and the cosmic ray experiments on the Space Station.

Advanced Solar Observatory (ASO)

The ASO is a dynamic system that will evolve with time, perhaps starting with P/OF, and then adding the SOT and the HRTC. Therefore, the first requirement is that the ASO Study Manager work with the Space Station systems engineers to define the interface between ASO and the Station.

The mass requirements cited for ASO refer to the instruments only and do not include supporting systems such as pointing mounts, platforms, and cabling. The pointing requirements refer to the High-Resolution Telescope Cluster as a unit and do not include the next higher level of control to be provided by internal image-motion compensation, which takes the instruments to their ultimate performance. The fundamental pointing requirement is to have a clear view of the Sun during all sunlit portions of the orbit. The data rates specified refer to that after data compression (which could be a factor of five) and for periods requiring maximum resolution (e.g., solar flares). The command rate is included to indicate the case in which the ASO is commanded from the ground; this will be the primary backup mode of operation. Electrical power is for the normal operations of all the Advanced Solar Observatory instruments. The temperature range is determined by the electronics requirements and by the need to avoid surface condensation. It should be noted that the ASO instruments will be especially sensitive to various types of contaminants, including hydrocarbons, particulates, and radiation.

To provide optimum operational interaction, a command and control console will be required inside the pressurized ASO module. This console will consist of (at a minimum) power panels for each of the ASO instruments; video and digital displays; controllers for the pointing mounts and instrument protective doors, controls for P/OF boom deployment and retraction; and at least two keyboards for controlling the instruments when necessary. The Space Station crew will be involved in the daily routine operations of the ASO, with additional personnel being required when intensive, nonroutine operations are carried out. Servicing and maintenance of the telescopes and instruments will be required periodically, and the crew will be required to make changes in focal plane instruments and to replace or upgrade other instruments.

Pinhole/Occulter Facility (P/OF)

Mass - 3,000 kg
Data rate - 1.4 Mbps
Command rate - 1.0 kbps
Internal volume - 3.0 m^3
Power to P/OF instruments - 0.500 kW
Power to the internal volume - 70 W

Solar Optical Telescope (SOT)

The most useful general statement one can make about the requirements which the SOT will impose on the Space Station is that the requirements for pointing accuracy and stability, command and control capability, data telemetry rate, and contamination control which the SOT imposes on the Shuttle also will have to be met by the Space Station. The requirements of the SOT, though less in some quantities than the total requirements of the HRTC, are representative of the requirements of the HRTC.

Mass - 4000 kg
Power across gimbal* - 5.0 kW
Pointing accuracy* - 2 arcsec
Pointing stability* - 0.1 arcsec
Data telemetry rate - 8 Mbps
Command rate - 2 kbps digital
Voice link for astronauts in station
Contamination requirements - to be determined

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*An Instrument Pointing System (IPS) or the equivalent is assumed to deploy the SOT.

Supporting Instrumentation for Evolved ASO

The requirements shown next refer to the High Resolution Telescope Cluster exclusive of the Solar Terrestrial Observatory. The large field telescopes for observing global magnetic structure and activity, global flows, global oscillation, and solar irradiance will in general not present special problems of compatibility with the Space Station that will not have been addressed by integrating the major elements of ASO. High energy instrumentation is likely to include cryogenics; an on-board resupply capability for the cryogen may be a useful and cost-saving simplification.

Mass - 12,500 kg
Pointing accuracy - 1 arcsec
Pointing stability - 0.1 arcsec
Data rate - 50 Mbps maximum with data compression
Command rate - 10 kbps
Power - 6.0 kW average, 8.5 kW peak
Temperature range - 0 to 30 C
Interior Volume 3m x 2m x 1m for operations console

Servicing Requirements

After initial placement and assembly of the major components, the evolutionary development of the ASO will require the capability to add new instruments and refurbish existing ones while they are in orbit. Expected activities include:

- Adding new instruments to the HRTC
- Replacing detectors
- Refurbishing optics
- Making repairs.

Occasionally, an entire cluster may be returned to Earth for major repairs or refurbishment.

Data System Requirements

The end-to-end data system for the ASO must be carefully designed for maximum utility and ease of use by the solar astronomer. During an intense observational "campaign", the ASO will probably produce data at a higher rate than any previous astrophysical instrument. Some of the expected requirements are discussed below.

Telemetry Rates. A peak downlink rate of 50 to 100 Mbps is expected once ASO has both P/OF and SOT, with an average rate of about 10 Mbps. As new instruments are added, this rate could double. The uplink rates are expected to be much more modest, but as the ASO evolves, uplink may reach 1 Mbps for control purposes and microcomputer loads.

Interfacing New Instruments. The evolutionary development of the ASO will require adding new instruments. The data system must therefore be designed for expanding easily and economically.

Real-Time Monitoring and Control. For many areas of solar research, near-real-time data access is required to facilitate decisions on pointing and instrument modes. With nearly continuous TDRS coverage, most of the objectives can be accomplished with a ground based facility that can quickly process and display images from ASO and send commands based on decisions by a team of solar astronomers. This facility would also require access to data from ground-based observatories such as magnetograms and H-alpha images.

On-Board Control and Monitoring. The ASO should be capable of complete control from the ground, using Space Station systems only as a link between the instruments and the observers. However, it will also be useful and desirable to have monitoring equipment on board the Station and some degree of real time control. This will be especially needed if the Space Station telemetry system cannot continuously provide high data rates to the ground.

Data Distributions. The volume of scientific information from ASO presents a challenging problem for data distribution, processing and analysis. Fortunately, the early Shuttle flights of the SOT should provide an excellent test case for development of a cost effective plan. In addition to scientific data from the instruments, ancillary data from the Space Station (such as attitude and environment data) will also need to be distributed regularly.

Cosmic Ray Experiments

Generally speaking, the cosmic ray instruments (CRNE/TRIC, SCMF, HEIE, and the HESS Array) have low data rates and require low power. They measure isotropic fluxes and hence are not concerned with fine pointing. All except HESS Array require counter gas resupply. The Superconducting Magnet Facility requires cryogen resupply. The principle requirement associated with HESS Array is accommodation of its large mass.

CRNE/TRIC

The panel on the manned base concluded that accommodating CRNE/TRIC would present no difficulty for the Space Station. Although the instrument is quite complex, its complexity is entirely contained within its pressurized shell and the only requirements are for a clear view of space, in the direction away from Earth, over a large field of view. Specific requirements are the following:

Power - 500 W
Data rate - 50 to 100 kbps
Pointing direction - Zenith
Field of view - +/- 90 degrees
Aspect information - 5 degrees
Stability rate - <0.1 degree/sec
Total mass - 6,000 kg
Nominal altitude - 500 km (not critical)
Orbit inclination - 28 degrees (not critical)

SCMF

Because superconducting magnet technology has been used in cosmic ray studies for 15 years, its operational and safety considerations are well understood. In addition, a full scale prototype magnet was constructed as part of the early HEAO program.

Besides requirements for setting up SCMF, periodically reconfiguring the investigations, and resupplying the superconductor with liquid helium, there are operational requirements for a clear view of space in the direction pointing away from Earth with no part of the Space Station in the instrument's field of view. This condition need not be maintained rigorously; even a 50 percent duty cycle would be satisfactory.

Additional requirements include:

Size/Volume: Cylinder = two pallets in length, diameter fits in Shuttle bay
Electrical power (electronics) - 1,000 W
Data rate - 100 kbps
Pointing direction - Zenith
Field of view - +/- 45 degrees
Aspect information - 5 degrees
Stability rate - < 0.1 degrees/sec
Total mass - 3,000 kg
Nominal orbit altitude - 500 km (not critical)
Orbit inclination - at least 28.5 degrees

The extent of the stray magnetic field is quite small compared to the scale of Space Station. At a distance of 1 meter from the instrument, the magnetic field is less than 30 times the strength of the Earth's magnetic field, and the field dies off rapidly (with the sixth power of the distance). The magnet is designed with two coils of opposite polarity, so no net torque would be exerted on the Space Station. The magnet can be charged and discharged by the Space Station crew. The dewar would be designed with a lifetime between ½ and 2 years, and would require that its cryogen (liquid helium) be resupplied as needed.

HEIE

The Cosmic Ray Program Working Group recommended HEIE for early flight on a space platform. This is an isotope spectrometer with a large collecting area (1 square meter) and a mass resolution of better than 0.2 amu, with precisely stable operation over a 6-month flight. This experiment will be designed to fit within the pressure vessel of CRNE/TRIC, and its requirements will be very close to those of CRNE/TRIC. It could also be accommodated on a platform of the Explorer class or moderate mission class.

Power - 300 to 500 W
Data rate - 30 to 100 kbps
Pointing Direction - Zenith
Field of view - +/- 45 to +/- 90 degrees
Aspect information - 5 degrees
Stability rate - <0.1 degree per second while the instrument is gathering data
Total mass - 2,500 to 5,000 kg
Nominal altitude - 500 km (not critical)
Orbit inclination - 90 +/- 45 degrees

Small Attached Payloads

In addition to the large solar and cosmic ray instruments described above, there exists another class of smaller payloads that are well-matched to the manned-base environment. Such payloads could be incorporated into the manned base with only a very modest impact on the overall configuration and resource allocations. A primary example of this class is gamma-ray burst studies. These experiments are generally modest in size, weight, telemetry, and power requirements. Zenith pointing is desirable, but inertial stabilization is acceptable. For a more detailed description of the scientific objectives and examples of instruments, the reader is referred to the section on the High Energy Transient Explorer in Volume 5, "Space Platforms for Astrophysics".

WORKSHOP ON
ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on
Space Station as a Manned Observation Base

Dr. J. David Bohlin, Chairman
Mr. Jack Barengoltz
Dr. Robert C. Golden
Dr. Hugh S. Hudson
Dr. Stuart D. Jordan
Dr. Joseph Klarman
Mr. James Marr
Mr. Edward Mettler
Dr. Ronald Moore
Mr. Robert G. Noblitt
Dr. Jonathan F. Ormes
Ms. Amelia Phillips
Mr. William Roberts
Dr. Richard A. Shine
Dr. Daniel S. Spicer
Dr. Arthur B. C. Walker, Jr.
Dr. George L. Withbroe

ASTROPHYSICS AND THE SPACE STATION

VOLUME 3

SATELLITE SERVICING FROM THE SPACE STATION

The idea of orbital servicing of satellites is not a new one to the Space Agency. The first significant attempt was a result of a launch-phase catastrophe during the Skylab mission. In that case, repair planning occurred only after the mission-threatening problem became evident. Because of the fatal nature of the problem, the emergency planning was performed at a high intensity and cost and at a significant risk. When the Skylab repair mission succeeded, the idea of in-orbit repair moved from concept to reality.

The advent of the Space Shuttle and the Multimission Modular Spacecraft (MMS) made orbital servicing more feasible and practical. With man in the orbital loop and a modular, repairable spacecraft, in-orbit satellite servicing concepts and the other conventional aspects of a mission were developed simultaneously. Planned servicing also offered the potential of lower cost, less panic, and less risk of failure. This concept was demonstrated successfully during the Solar Maximum Repair Mission.

Now, satellite servicing is maturing to its full potential. It is an integral part of the design of each member of a fleet of new astronomical observatories planned (Advanced X-Ray Astrophysics Facility and Space Infrared Telescope Facility) and under development (Hubble Space Telescope and Gamma Ray Observatory). The Space Station has the potential to service the observatories more effectively and make servicing practical for a broad range of platforms. The Space Station offers enhanced servicing capability with long servicing visits.

Benefits of enhanced servicing include:

- Repair/replacement of failed subsystems (in orbit or after retrieval/return to earth)
    - ensures against premature termination of mission
    - allows more risk acceptance during mission development.

- Technological upgrading/replacement of obsolete equipment
    - upgrades instruments in telescope focal planes
    - upgrades subsystems to improve performance.

- Platform support
    - enables reuse of spacecraft (experiment hardware exchanged in orbit or on ground)

- allows spacecraft (platforms) to be amortized over several missions
- allows experiment hardware to be upgraded and reused.

These applications, beyond simply fixing something that does not work, provide a vastly greater return on our economic and scientific investments in space research.

The purpose of Volume 3 is to define servicing concepts and requirements for both the Space Station and its satellite users so that this capability can be best utilized by the astrophysics community. Although astrophysics missions are well-suited to servicing concepts because of the frequent use of a 28.5-degree orbit (compatible with the Space Station), most of the discussion in this volume has broad applications.

SATELLITE SERVICING IN THE ASTROPHYSICS PROGRAM

For astrophysics, the present is an opportune time to be planning for the future. The Solar Maximum Repair Mission, which restored a valuable observatory for another several years of pioneering research, convincingly demonstrated the crucial role of satellite servicing in a successful astrophysics research program in space.

Planned satellite servicing in space is a major new capability with profound significance for the future of astrophysics. Indeed, routine orbital servicing is every bit as important to our science planning as advanced detector technology. Such servicing may be considered a new "technology", for it will mandate technological advances in fluid transfer and other servicing techniques.

The emergent capability to maintain, repair, and retrofit our instruments and spacecraft in space can shape the course and character of astrophysics research through the rest of this century and into the next. With optimism, we foresee the exploitation of this new capability in the Space Station era. Furthermore, we anticipate great progress in astrophysics research as our facilities gain extended lifetimes and greater versatility through in-orbit servicing.

Servicing Roles

What is the nature of this new technology, and what does it offer the astrophysics program--both practically and conceptually? Satellite servicing is the repair, replacement, or maintenance of hardware in space, a function made possible by the Shuttle, which provides access to low Earth orbit, and by the Space Station, which will provide a permanent, manned base for various activities in space. Servicing also involves resupplying con-

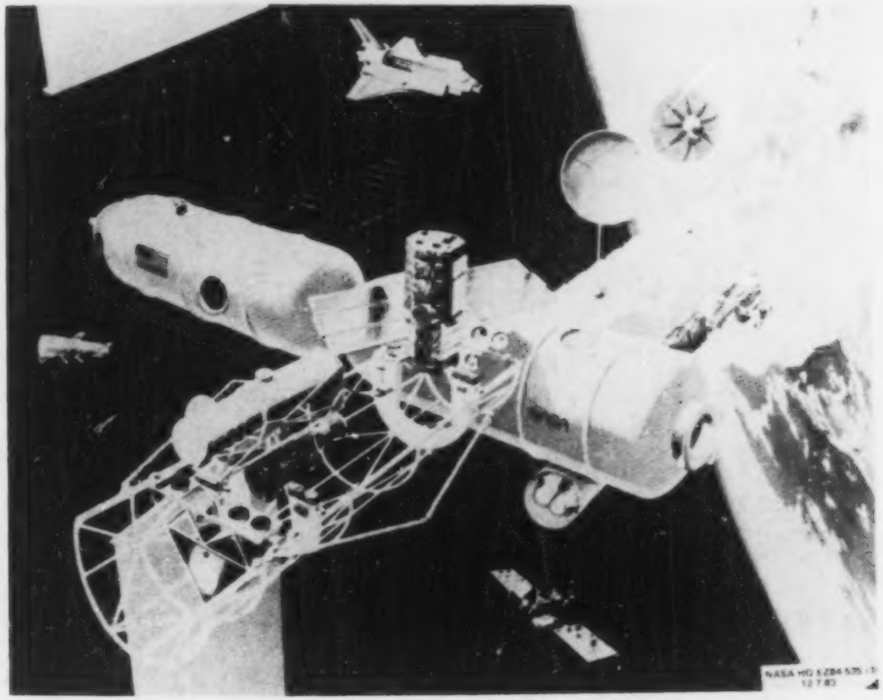

FIGURE 3.1. SERVICING ASTROPHYSICS MISSIONS AT THE SPACE STATION

This picture shows one concept for servicing spacecraft and astrophysics missions at the Space Station. The Solar Maximum Mission is shown in the Flight Support System (FSS) used in the Solar Maximum Repair Mission.

sumables such as cryogens or propellants, cleaning optical surfaces, recharging batteries, making fine adjustments, calibrating instruments, and performing other "housekeeping" tasks.

In addition, servicing at the Space Station allows for an entirely new mode of operation for observatory-class facilities. Routine changeout, with or without upgrading, permits flexibility and evolution in the instruments and extends the useful scientific lifetime of the observatories in the same way that maintenance and replenishment increase their physical lifetime. Instrument changeout is more complex than simple component replacement and replenishment. It involves handling complex subsystems, alignment and, perhaps, recalibration. Such operations require the space, facilities, and time that are available with the Space Station but not with the Space Shuttle. It may also require that intricate work be carried out in the "shirtsleeve" environment of a Space Station laboratory or hangar, another capability that is impossible in the cramped quarters of the Space Shuttle.

From our experience in the past Skylab era as well as the Solar Maximum Repair Mission, we perhaps conceive of satellite servicing as a function performed by an astronaut-mechanic equipped with an Extra-Vehicular Activity (EVA) tool kit and some special mobility aids and grappling devices. For the Space Station era, however, this "Mr. Goodwrench" concept is too simplistic. We contemplate at least four major, complex servicing roles for astrophysics missions in the near future. The Space Station should be the nexus for all of these functions.

Repair

The most readily apparent servicing function is the repair or replacement of failed or degraded parts. Failures at the system, subsystem module, component, or piece-part level jeopardize every mission. The best design in the world, complete with redundant systems in all critical areas, does not guarantee against random failures or limited life-cycle parts in today's complex instrumentation. Given the fact that some failures and wear-outs are inevitable, the challenges facing us as we plan astrophysics missions are to identify repairable and/or replaceable elements, develop a servicing philosophy, and design our hardware appropriately to implement that philosophy. That is, we must make those serviceable elements accessible and readily manageable in space; we must develop standardized, rather than customized, parts and interfaces; and we must provide the capabilities needed in orbit for EVA, shirtsleeve, automated, and remote servicing tasks. The Multimission Modular Spacecraft, for example, is designed for repair. Although not so designed, parts of the Solar Maximum observatory's instrument complement proved repairable with some ingenuity.

No longer must we use hindsight to determine how to repair space hardware, however. The Shuttle and Space Station give us the opportunity to use foresight and careful design to restore failed or degraded parts, thereby extending the useful life of our spacecraft. By making our instruments easily serviceable in orbit, we may also be easing the task of system integration and test on the ground, since ground-accessibility will also be improved. Both the Shuttle and the Space Station will, however, continue to play important roles in servicing because of the limitations on Space Station access to missions having a different orbital plane. For a mission like Hubble Space Telescope (HST), the periods for possible Space Station access and service are spaced at several year intervals. During intermediate times, only the Shuttle can be used to rescue and fix a "sick" space telescope. Thus, the Space Station will be the regular service station and the Shuttle the "breakdown van" of the 1990's.

Maintenance

A second servicing role is the maintenance of our orbital observatories, major new facilities with expected operational lifetimes of 10 to 20 years or longer. This spacecraft class includes the Hubble Space Telescope (HST), the Advanced X-Ray Astrophysics Facility (AXAF), the Gamma Ray Observatory (GRO), and the Space Infrared Telescope Facility (SIRTF), as well as the Solar Maximum Mission (SMM). There is compelling justification for servicing these observatories, because of our large investment in their development and because of the scientific necessity for their existence. The orbital observatories embody our aspirations to understand the origin and history of the universe, and they will be our prime tools for discovery in the years ahead.

Upgrade

Servicing satellites involves not only routine maintenance, resupply of consumables, and repair of broken parts, but also periodic upgrading of the instruments with new technology. The mirrors themselves will be the finest possible, with unprecedented quality, and we do not expect them to become obsolete. However, detector technology advances so rapidly that it is desirable to maintain state-of-the-art instrumentation at the focal plane. The new servicing capability enables us to upgrade observatories by exchanging focal plane instruments as technology yields improved sensitivity and resolution.

Since discovery keeps pace with technology and each increase in sensitivity reveals more faces of the unknown, upgrading our major observatories is crucial to astrophysical research in space.

Another innovative servicing role is the support of modest-scale missions in the Explorer or Proteus class. We envision a fleet of standardized free-flyer buses capable of carrying several different payloads, with each bus having a lifetime of 10 to 15 years. Like the Multimission Modular Spacecraft currently used for observatory-class payloads, such as Landsat and Solar Max, the reusable bus would consist of standardized serviceable parts and a standardized instrument interface. An instrument set mated to the bus would operate for 2 to 3 years and then be removed, in orbit, for replacement by a new payload of instruments with perhaps an entirely different research agenda.

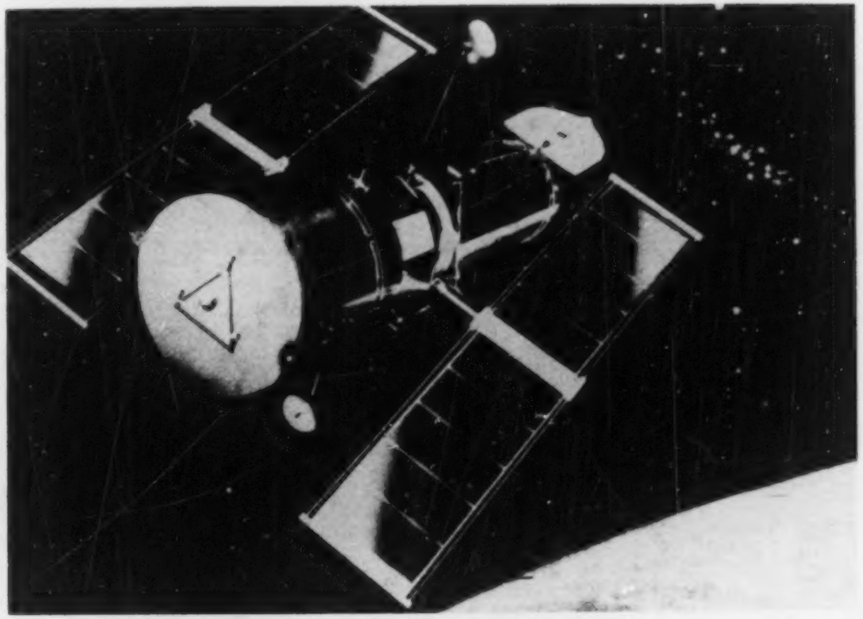

FIGURE 3.2. THE HUBBLE SPACE TELESCOPE (HST)

In addition to its scientific instruments, the major spacecraft systems of HST are modular and designed to be replaced in orbit. Much more of HST becomes serviceable at the Space Station. HST and the other observatories are described in the Appendix to this volume.

Delivery and Retrieval

A fourth significant servicing role is the delivery and retrieval of satellites. The use of space-based, reusable, low and high energy transfer vehicles to deliver newly launched spacecraft from the Space Station to operational orbit will extend the cost benefits provided by the Shuttle as a delivery vehicle. The use of the Space Station as a transportation node will be further enhanced by efficient retrieval of malfunctioning or obsolescent spacecraft and transport to the Space Station for maintenance, repair, or retrofit. An additional servicing benefit is the cost-effective reboost of functional spacecraft into operationally more effective orbits by reusable transfer vehicles, based on the Space Station, rather than by dedicated Shuttle missions.

As the new servicing technology evolves, so will our philosophy of mission planning. Instead of designing a spacecraft to accommodate preselected scientific objectives, we will be able to tailor science to the flexible capabilities of multimission spacecraft. We will also be able to improve our capabilities to meet future mission requirements by upgrading these serviceable spacecraft. We envision using the same bus, with no redesign, for different kinds of missions, such as Sun pointing, stellar pointing, Earth pointing from low-Earth orbit, and Earth pointing from geosynchronous orbit. A versatile, serviceable spacecraft offers many mission opportunities. Standardization of certain spacecraft elements and designs need not limit our imaginative planning for astrophysics research in space.

Servicing Philosophy

The thrust of all these servicing functions--repair, observatory maintenance, mission support, and orbit transfer--is the same: to use and maintain our capital assets in space. Satellite servicing is the key to gaining the most value from these facilities. Rather than accept failures that convert sophisticated spacecraft into expensive junk, we will adapt and repair our assets. Furthermore, the focus will be on space repair operations with ground return as a last resort. This will help to avoid subjecting flight equipment to the hostile environment of a round trip back to space, avoid nonessential repairs, and minimize a large support staff on the ground.

The attractive option, then, is to take advantage of the new servicing capabilities afforded by the Shuttle and Space Station. It is time to implement a reasoned servicing philosophy in the design of spacecraft and scientific instruments. It is also time to specify the standardized interfaces and servicing requirements for spacecraft design and to identify the servicing resources needed on the Space Station.

Logistics Standardization

Inherent in the concept of satellite servicing is the concept of logistics standardization. It is very expensive to service one-of-kind components custom-designed for a particular mission. The logistical problem of stocking unique parts and training crew members to service each different part make standardization attractive, at least for elements common to many spacecraft (e.g., subsystems, star trackers, batteries). On the other hand, scientific instruments by their very nature obviously are unique and, except for interfaces, do not lend themselves to standardization. Furthermore, by common spacecraft bus, subsystems, and component sharing, more room will be available for storing unique, replaceable scientific instruments aboard the Space Station. Standardization of serviceable spacecraft elements is another way to improve funding for science instrumentation through common and shared use of spare spacecraft equipment.

Serviceable space systems are already taking logistics standardization into account. The Space Transportation System has to sustain an inventory to support the Space Shuttle and its elements. The Space Telescope is similarly committed to support its system, as is the Multimission Modular Spacecraft. To ease its logistics problems, the Space Station will go one step further and attempt to use common elements across all its modules.

New spacecraft should use systems, subsystems, and components from existing inventories or from newly defined Space Station and space platform components where feasible. In some instances, market conditions will force new designs, which can be constrained to meet existing interfaces and to provide new capability. If these elements are not standardized, the cost of ownership of long-lived systems will so dominate the budget that new development opportunities will be curtailed. The astrophysics program must move toward standardization in spacecraft design, at least at the interface level, if we are to reap the most scientific benefit from the new servicing technology.

Effective spacecraft servicing has the promise of dramatically increasing our scientific understanding. With sophisticated observatories in space and long periods of observation, it may be possible in our lifetimes to exceed the number of all previous discoveries about the nature and history of the universe. Orbital servicing can extend mission lifetimes threefold or more, enabling more scientific investigations through reuse of existing facilities. In this context, use of observatories in space would more nearly resemble the continuous use and reuse of observatories on the ground.

Human Productivity

Besides conserving hardware by extending the useful lifetimes of existing satellites, orbital servicing conserves an equally valuable commodity: human effort. The design, construction, and use of a scientific satellite involves years of work by many people. In particular, scientists may devote 10 years of their career to seeing a concept brought to fruition.

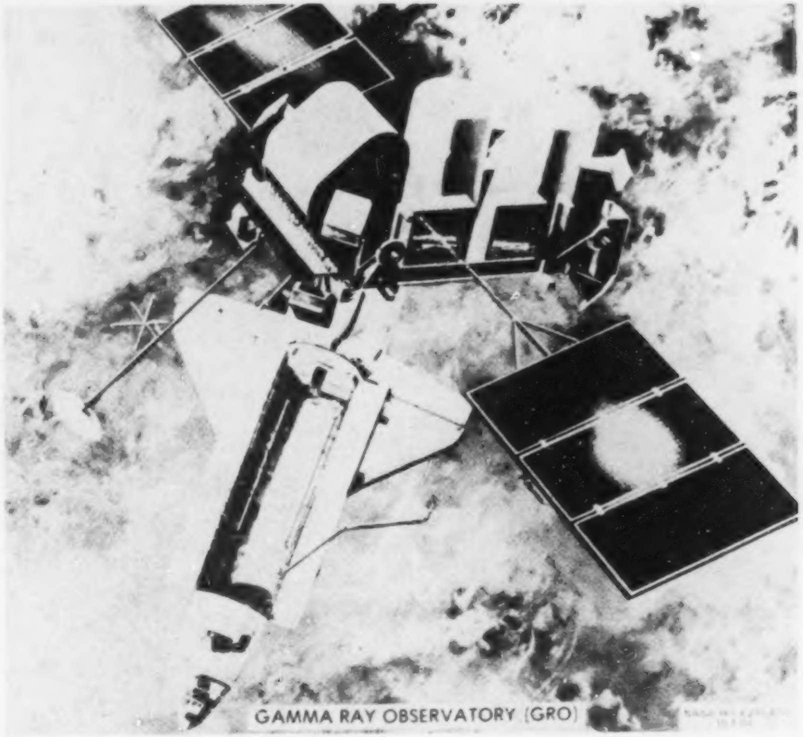
GAMMA RAY OBSERVATORY (GRO)

FIGURE 3.3. THE GAMMA RAY OBSERVATORY (GRO)

Low altitude is an important scientific requirement for this mission. To extend the mission's lifetime, the propulsion system can be refueled in space.

if the satellite or instrument then fails, whether or not they foresee the reasons, those people have squandered their own most valuable resource--time. Thus, satellite science offers impressive rewards, but only with great risk.

By repairing and improving satellites, it is possible to safeguard this personal (and national) investment. Lessened risk also will enable more scientists to become involved in space science, to the great benefit of astrophysics. Furthermore, by use of multi-purpose platforms, spacecraft development schedules will no longer pace the development cycle; proven instruments may fly on much shorter time scales than at present. In-orbit servicing inevitably leads to optimal use of scientific instruments by preventing loss or diminution of capability. Our human scientific resources also will be better utilized.

As both the scientific objectives and the requisite instruments for modern astronomy and astrophysics grow increasingly more complex and more expensive, we need to develop more economical means to achieve our scientific goals. Orbital repair, maintenance, and upgrading hold promise, both economically and scientifically, for enabling us to make the discoveries that surely await us.

SATELLITE SERVICING AND THE SPACE STATION

While the Shuttle has made satellite servicing possible, the Space Station offers dramatically improved capabilities and resources for performing repair, maintenance, and refurbishment activities in space. To appreciate more vividly the advantage of a Space Station service center for astrophysics missions, consider the following analogy.

For some 40 years, the Palomar Observatory has been one of the premier astronomical research facilities in the world. Its longevity despite the explosion of high technology is due to regular maintenance and periodic upgrading to introduce new technology in the focal plane. The value and versatility of the observatory have kept pace with advances in detector and computer technology, and through continuous operation for four decades the observatory has contributed vastly to our knowledge of the universe. Palomar is a major asset for the nation and the scientific community; the same can be said of our new orbital observatories.

The Space Station permits servicing an orbital telescope in a manner comparable to the way the Palomar Observatory is maintained: with more time for servicing at a relaxed pace, greater flexibility in work schedules and supply delivery, and a relatively clean environment. The Space Station should ultimately include a shirtsleeve environment hangar, which will make it possible to perform major refurbishment in space and thereby avoid the attendant costs and risks of returning spacecraft to the ground.

As we plan for servicing at the Space Station, we must answer the following questions for each candidate mission: What elements or subsystems require routine servicing or maintenance? What parts are most likely to fail? What can be fixed? What can be replaced? What can be done remotely or by automation? What can be done by EVA? What must be done in a shirtsleeve environment? What kind of additional science can we do with in-orbit servicing capabilities? Identifying repairable and replaceable parts is the first step toward designing a serviceable spacecraft and a service center that meets the customer's needs. These servicing and design requirements are described in considerable detail later in this volume.

Maintenance Echelons

We also must develop a maintenance philosophy that guides our design, best serves science by assuring long-lived missions, and most economically utilizes the Space Station for servicing. Here we can learn valuable lessons from past experience in space and also from commercial and military organizations with similar maintenance and logistical demands to keep their hardware in service.

In particular, the military concept of maintenance echelons is applicable to satellite servicing in space. First-echelon maintenance, the least complex level, involves elements designed for repair-by-replacement. These tasks may be accomplished in space by EVA, remotely operated devices, or automation; they typically involve removal and reinstallation of units equipped with quick-disconnect features, such as MMS-type modules. Second-echelon maintenance involves repairable or replaceable elements that are not necessarily designed for servicing. This task can be done by EVA and is of intermediate complexity. Servicing of the main electronics box on Solar Max exemplifies the second echelon of maintenance. In the military, these first- and second-echelon activities are performed in the field.

The third and fourth echelons of spacecraft maintenance would occur on the ground today, but in the Space Station era they could occur in a shirtsleeve environment in space. In the military, these activities are performed at a depot rather than in the field. In third-echelon maintenance, black boxes within systems would be replaced or simple tasks would be conducted on subsystems small enough to be accommodated in a pressurized module or lab, while in Echelon Four, an entire spacecraft or major subsystem would be brought into a pressurized hangar for major repair or overhaul.

By the same analogy, resupply of consumables can be thought of in echelons. Echelon 1 resupply is accomplished by fluid transfer and Echelon 2 by canister replacement, both in EVA operations. Both at Echelon 3 (subsystem fluid and canister replacement) and at Echelon 4 (system fluid and canister replacement), resupply operations occur in a shirtsleeve environment.

Preliminary studies indicate that it will be exorbitantly expensive to bring observatory-class instruments to the ground for Echelon 3 and 4 servicing. Cost estimates for full refurbishment range as high as 50 percent of the original development cost of observatory systems. Furthermore, the delicate telescopes will be subjected to G-loads, vibration, and contamination during return and landing. Just as the military strategy is to keep vehicles and systems in service with minimal downtime, so our strategy for astrophysics missions must be to keep our telescopes in space and keep them working there. While return of smaller, less complex spacecraft may be feasible, the economically practical approach to large-scale servicing is to do it in space.

The Space Station offers such an opportunity. Ideally, a Space Station service center will provide facilities for both EVA tasks (first and second echelons) and shirtsleeve tasks (third and fourth echelons) for planned maintenance, and Shuttle facilities for first- and second-echelon contingency maintenance. Missions in the astrophysics program must be evaluated to determine what maintenance planned to be done on the ground could be done in space given an appropriate Space Station environment. Development of a maintenance philosophy covering all four echelons is imperative for astrophysics missions in this new era.

THE ASTROPHYSICS MISSIONS AND THEIR SERVICING REQUIREMENTS

Survey

To develop a valid servicing philosophy for astrophysics missions, we should understand the servicing needs of the payloads and identify the spacecraft and payload hardware that can be serviced. As part of the June 1984 workshop deliberations on Astrophysics Utilization of the Space Station, the spacecraft servicing group conducted a survey to identify the servicing requirements of 24 near-term and possible future astrophysics missions. During the workshop, a panel of scientists, program managers, and satellite servicing experts convened to review the results of the survey and prepare this document for publication. As the draft was subjected to critical scrutiny, the group refined the servicing concepts foreseen for astrophysics missions and specified requirements for both the Space Station and its astrophysics users. This document represents the consensus of key members of the astrophysics community who are responsible for the planning, design, and scientific objectives of serviceable astrophysics missions.

The appendix to this volume summarizes some of the missions surveyed. (Missions selected for the study were those having, at present, the most complete technical definition. For missions not yet approved, inclusion in this report does not imply priority). The purposes of the survey were to collect detailed information about planned spacecraft/payload design and anticipated servicing tasks, and also to stimulate creative thought about taking advantage of the servicing capabilities that are possible on the Space Station.

The survey was conducted in four steps. First, a team of spacecraft servicing authorities developed a questionnaire to assess the servicing potential of each mission. Then, members of this group solicited information from principal representatives of the astrophysics community and completed a questionnaire for each mission.

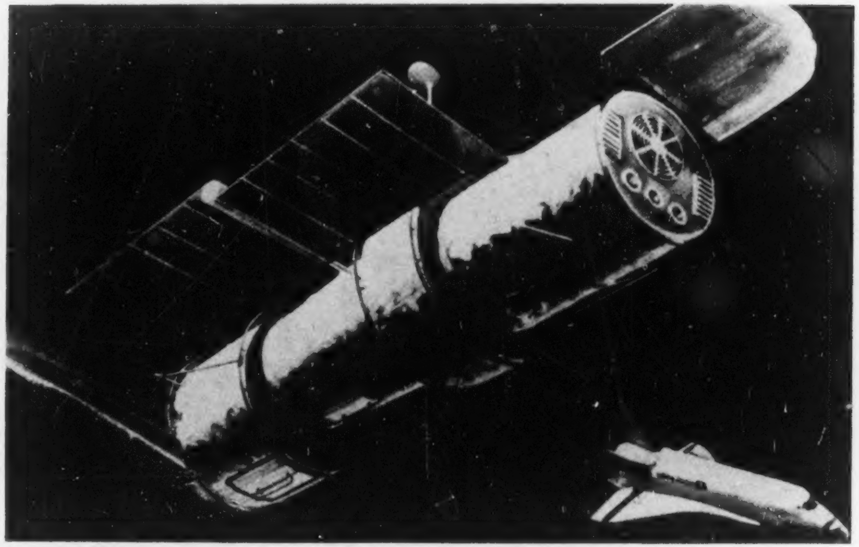

FIGURE 3.4. THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)

X-ray observatories are so important to modern astrophysics that AXAF will be designed as a permanent observatory in space; it is a candidate mission for a dedicated Space Station platform.

From the completed questionnaires, the group extracted critical information and plotted a matrix of servicing functions for all missions. Results are presented here as Tables 1 through 3; Table 4 is a servicing schedule, also derived from the questionnaires. Finally, from this matrix were derived the servicing requirements of astrophysics missions and the definition of Space Station capabilities necessary to meet these servicing needs.

Key Candidate Systems for Servicing

From the survey, we found that some spacecraft systems and components are better candidates than others for in-orbit servicing (replacement, adjustment, or repair). The key candidates for in-orbit servicing are:

- Scientific instruments that may be replaced with higher technology sensors or with instruments designed to collect different data
- Systems that require replenishment of consumables
- Limited-lifetime components expected to degrade with use
- Failures that could damage the spacecraft or limit its usefulness and for which redundancy cannot be provided
- Technologically limited equipment with a high probability of degradation
- Easily replaceable hardware, since the cost of providing the servicing capability may be low
- Orbital altitude maintenance.

Other Key Findings

An analysis of the information on the questionnaires revealed that in-orbit servicing is highly desirable for all surveyed payloads and that servicing from the Space Station has advantages over servicing from the Shuttle. Other key findings are as follows:

- All astrophysics missions studied require, or can use, some type of in-orbit servicing.
- Less than 10 percent of the missions require only contingency servicing. The rest plan routine and/or upgrade as well as contingency servicing.

TABLE 1. NEAR-TERM AND POSSIBLE FUTURE ASTROPHYSICS MISSIONS INCLUDED IN SURVEY*

Mission	Acronym	Launch
FREEFLYERS		
Observatories		
Hubble Space Telescope	HST	1986
Gamma Ray Observatory	GRO	1988
Advanced X-Ray Astrophysics Facility**	AXAF	early 1990's
Space Infrared Telescope Facility**	SIRTF	early 1990's
Moderate and Explorer Missions		
Advanced Low Energy Gamma-Ray Explorer	ALEGRE	TBD
Astrometric Explorer	AE	mid-1990s
Cosmic	COSMIC	early 2000's
Far Ultraviolet Spectroscopic Explorer	FUSE	early 1990's
High Energy Transient Explorer	HETE	early 1990's
High Through-Put Mission	HTM	TBD
Large Deployable Reflector	LDR	late 1990's
Near Infrared Sky Mapper	NISM	TBD
Solar Corona Diagnostics Mission	SCDM	mid-1990's
Solar Maximum Mission	SMM	1980, 1984
Spacecraft Array for Michelson Spatial Interferometry	SAMSI	early 2000's
Space Platform Interferometer	SPI	mid-1990's
Starlab	STARLAB	mid-1990's
X-Ray Timing Explorer	XTE	early 1990's
PAYLOADS ATTACHED TO THE SPACE STATION		
Cosmic Ray Nuclei Experiment/TRIC	CRNE/TRIC	early 1990's
High Energy Space Station Array	HESS Array	mid-1990's
Solar Optical Telescope	SOT	TBD
Advanced Solar Observatory	ASO	early 1990's
Solar Terrestrial Observatory	STO	mid-1990's
Superconducting Magnet Facility	SCMF	mid-1990's

*These are mostly candidate future missions; no priority is intended.

**Space Station platforms may be used as the basis for these missions to improve commonality of components and interfaces.

TABLE 2. ASTROPHYSICS FREE-FLYER MISSION POTENTIAL SERVICING REQUIREMENTS

	HST	GRO	AXAF	SIRTF	SMM	STARLAB	HTM	LDR	SAMSI	COSMIC	HETE	FUSE	XTE	AE	SCOM	NISM	ALEGRE	SFI	TOTAL
Systems Requiring Service																			
Instruments	X		X		X			X		X					X		X	X	8
Spacecraft	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X			15
Subsystems	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	18
Components	X		X	X	X	X				X	X	X	X		X	X		X	12
Systems Designed for Service																			
Instruments	X		X					X		X			X		X		X	X	8
Spacecraft	X	X	X	X	X		X		X	X	X	X	X	X	X	X			14
Subsystems	X	X	X	X			X	X	X	X	X	X	X		X	X	X	X	15
Components	X									X		X			X	X		X	6
None						X													1
Capture Technique(s)																			
OMV			X	X	X			X	X	X	X	X	X	X	X	X			12
OTV						X		X				X	X		X	X		X	7
RMS	X	X	X	X	X	X			X	X	X	X	X	X	X	X		X	15
MMU					X				X		X	X	X		X	X		X	8
Attached P/L																			0
Service Site																			
Berthing Platform (FSS)	X	X	X	X	X	X				X								X	8
Surrogate Bay	X	X							X	X		X		X	X	X			8
Attached Payload Site																			0
Shirtsleeve (Subsystem)	X		X	X	X			X	X	X					X				8
Shirtsleeve (Observatory)	X			X	X														3
In-Situ								X											1
Type of Service																			
Routine		X	X	X	X			X	X		X		X		X	X	X		11
Contingency	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	16
Upgrade	X		X	X	X		X	X		X		X			X	X	X	X	12
Maintenance Echelons of Service																			
Routine		1	1,2	1 or 3	1,2,3,4			1			1		1						
Contingency	1,2,3	1	1,2,3,4	1,2 or 4	1,2,3,4	1,2	TBD	2,3,4	1,2,3,4	1	1	1	1	TBD	1	1		3	
Upgrade	1		1	2,3,4	1,2		TBD	TBD		1		1			1	1			
Resupply Echelon																			
Routine		1	2	1 or 3	3			1	1		1,2	1	1		1	1	2		
Contingency							1			1									
Cycle of Service																			
Routine		2.25 yrs	3 yrs	1.5 yrs	2 yrs			3-6 mos	10 days		1 yr		3 yrs			1-2 yrs	0.5-1 yr		
Contingency	4-5 yrs	2.25 yrs		5-10 yrs	4 yrs		5 yrs			2 yrs									
Upgrade	2.5 yrs			5-10 yrs	4 yrs		5 yrs			2 yrs		2-5 yrs						1-3 yrs	
Consumable	none	N_2H_4	propane N_2H_4, TBD gas mix	LHe LH_2	propane	none	N_2H_4	LHe	TBD fuel LHe	LHe, LH_2	N_2H_4 CH_4,NH_3	N_2H_4	N_2H_4		N_2H_4	N_2H_4 LH_2	Solid Cryogen		
Mission Life																			
Without Service	2.5 yrs	2.25 yrs	3 yrs	2 yrs		0.5-1 yr	5 yrs	N/A	10 days	2 yrs	1 yr	3 yrs	3 yrs	5 yrs	TBD	1-2 yrs	0.5-1 yr	1-3 yrs	2 yrs
With Service	10+ yrs	4.5 yrs	15 yrs	10-15 yr		indef.	10 yrs	15 yrs	10 yrs	indef.	5 yrs	10-20 yrs	6 yrs	N/A	TBD	5-10 yrs	3 yrs	indef.	9.5 yrs

TABLE 3. ASTROPHYSICS SPACE STATION ATTACHED PAYLOADS' POTENTIAL SERVICING REQUIREMENTS

	CRNE/TRIC	SCMF	SOT	ASO	STO	HESS Array	TOTAL
Systems Requiring Service							
Instruments			X	X	X	X	4
Spacecraft						X	1
Subsystems	X	X	X		X	X	5
Components			X		X	X	3
Systems Designed for Service							
Instruments					X	X	2
Spacecraft						X	1
Subsystems	X	X	X	X	X	X	6
Components					X	X	2
None							0
Capture Technique(s)							
OMV							0
OTV							0
RMS				X	X	X	3
MMU					X		1
Attached P/L	X	X	X	X	X	X	6
Service Site							
Berthing Platform (FSS)							0
Surrogate Bay	X			X			2
Attached Payload Site	X	X	X	X	X	X	6
Shirtsleeve (Subsystem)		X					1
Shirtsleeve (Observatory)							0
Type of Service							
Routine	X	X	X	X	X	X	6
Contingency			X	X	X	X	4
Upgrade			X	X	X	X	4
Maintenance Echelons of Service							
Routine			1	1,2,4	2,4	1	
Contingency				1,3	2,4	1	
Upgrade				1	2	1	
Resupply Echelon							
Routine	1	1	1		1,2	2	
Contingency							
Cycle of Service							
Routine	0.5 yr	0.5 yr	TBD	0.5 yr	0.5 yr	2 yr	0.5 yr
Contingency							
Upgrade							
Consumable							
	He-Xenon-Methane, Neon-CO_2	LHe Argon-Methane	Film	Film	N_2, Argon, Xenon	Solid target material, film	
Mission Life							
Withuut Service	0.5 yr	0.5 yr.	7 days	1 yr	0.5 yr	2 yr	0.5 yr
With Service	Indef.	Indef.	Years	10 yrs	10 yrs	10 yrs	Indef.

TABLE 4. POTENTIAL SERVICING SCHEDULE*

	1986	87	88	89	90	91	92	93	94	95	96	97	98	99	2000
Space Station							▽								
Free Flyer Mission															
Observatory Class															
HST	▽			●		●			●		●			●	
GRO			▽		●			●							
AXAF						▽			●			●			●
SIRTF							▽		●	●		●	●		
Moderate Class															
SMM	●		●		●		●								
Starlab										▽	C				
HTM					(launch date TBD)										
LDR											▽		●		●
SAMSI															▽ 18
COSMIC															▽
Explorer Class															
FUSE						▽			●			●			
XTE						▽			●			●			
HETE							▽	●	●	●	●				
NISM								▽		●		●		●	
AE									▽		C				
SCDM									▽			●			
SPI									▽		●		●		●
ALEGRE										▽	●	●	●		
Free Flyer Total	1	0	1	1	2	1	1	2	6	2	4	11	7	6	6

* - data derived from questionnaire

▽ - launch

● - planned servicing

C - contingency servicing only

- Routine servicing can greatly enhance the scientific value of a payload.
- Most missions plan first- and second-echelon servicing, with third- and fourth-echelon repair in a contamination-free, shirtsleeve work area offering the ability to reduce inventory requirements.
- To preclude the need to return observatories to the ground for major refurbishment, a contamination-free, shirtsleeve facility with good access to large systems and subsystems is required.
- Spacecraft retention and positioning systems are required for servicing free-flyers at the Space Station.
- Commonality of support systems should be a prime consideration in the observatory design.
- Modes of consumable resupply at the Space Station will include recharge from storage tanks or dewars and canister replacement.
- Ease of training for the servicing crew should also be a strong consideration.
- Leased platform services' program requirements are similar to AXAF, SIRTF, and Space Telescope except service frequency is every 6 months.
- In-orbit servicing can assure the design lifetime and also greatly extend the useful life of astrophysics observatories.
- Short-term missions (~0.5 years) can be extended to years.
- Long-term missions (~2 years) can be extended to 10-15 years (or longer).
- Contingency servicing may still be done from Shuttle because of orbital plane mismatches with the Space Station.

SPACE STATION REQUIREMENTS FOR SPACECRAFT SERVICING

The Space Station, planned for initial activation in the early 1990's, will provide a permanent base for routine maintenance, repair, and upgrading of free-flyer spacecraft and scientific payloads attached to the Space Station itself.

The requirements presented in this section are derived primarily from two sources: plans for future missions (ascertained by survey conducted by the spacecraft servicing group) and lessons learned from past and current

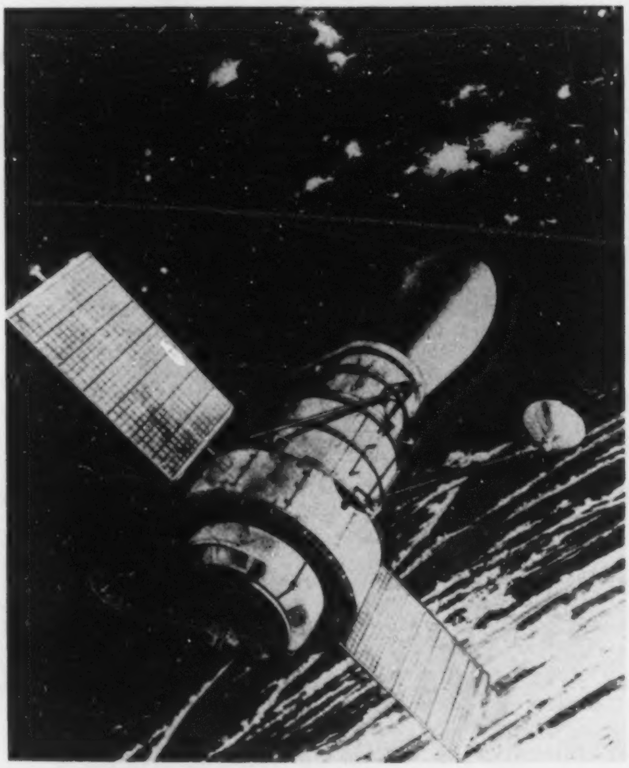

FIGURE 3.5. SPACE INFRARED TELESCOPE FACILITY (SIRTF)

Cold optics and sensors are required for sensitive observations of the processes of stellar birth, and SIRTF is designed so that superfluid helium can be supplied in space to keep the telescope within a few degrees of absolute zero. SIRTF is another candidate mission for a dedicated Space Station platform.

experience. The feasibility of in-orbit repair and maintenance has been demonstrated well in the Skylab era, in Shuttle missions, and in the crew training activities for Space Telescope and Spacelab. The Solar Maximum Repair Mission dramatically confirmed the value of Shuttle-based servicing and set the stage for the Space Station as an orbital service center.

A concerted effort to infuse sound lessons learned into futuristic planning is necessary if we hope to use the Space Station for our optimal benefit in astrophysics research. Many servicing concepts and techniques have been evaluated in 0-g and 1-g simulations. Also, proven hardware exists for a variety of servicing functions, and a modular, standardized spacecraft bus (the MMS) is already in use. This invaluable practical experience must be introduced into mission planning and design activities early enough and with conviction enough to influence the course of Space Station and future spacecraft designs.

Satellite Servicing Center

Location of the satellite servicing center on the Space Station should be selected with consideration of the following:

- EVA Translation Paths
- Contamination
- Lighting
- Thermal Control
- Radiation (all kinds)
- Particle Protection.

The Space Station based service center should be equipped with the necessary support hardware to perform the required service activities:

- A spacecraft berthing and positioning system with tilt and rotate capability, standard berthing interface and electrical umbilical mate/demate mechanisms
- A spacecraft payload retention system duplicating the Shuttle Orbiter payload retention system and electrical interfaces
- A spacecraft/payload storage area to accommodate spacecraft awaiting servicing or Shuttle-delivered payloads to be mated to spacecraft
- Station Manipulator System with Manipulator Foot Restraint (MFR)

- Manned Maneuvering Unit (MMU)
- Refueling capability for gases, fuels, and cryogenic fluids
- Stowage sites for replacement modules, instruments, electronic hardware, and test equipment
- Outgassing sites for spares previously stored or repaired in a pressurized environment or recently arrived on the Shuttle
- Tools and tool storage areas
- EVA support equipment--foot restraints, handrails, slidewires, and tethers
- Orbital Maneuvering Vehicle (OMV) and docking port
- Advanced Extravehicular Mobility Unit (EMU)
- Accommodations for assembly and servicing of larger spacecraft
- Shirtsleeve work environment for detailed corrective and upgrading tasks (i.e., piece part and component changeout) with adequate access for science instruments and other fixable subsystems
- Robotic system for performing routine mechanical activities without EVA requirement
- Orbital Transfer Vehicle (OTV) to support remote automated servicing of spacecraft
- On-orbit checkout equipment and crew training aids.

Spacecraft Berthing and Positioning System

A spacecraft berthing and positioning system, with tilt and rotate capability, is needed to act in concert with the station manipulator system to provide servicing access to the entire exterior of spacecraft being serviced. This system should incorporate standard berthing latches for spacecraft restraint and electrical umbilical mating drives to provide electrical power for control and monitoring of spacecraft systems. This platform should be located to provide the maximum clearance for solar arrays and other appendages. However, to minimize potential hazards to the EVA crew and/or spacecraft, these items should be retractable.

Spacecraft and Payload Retention System

A retention system duplicating Shuttle orbiter payload retention system interfaces is required to restrain Shuttle-delivered spacecraft and payloads awaiting servicing, payload/spacecraft mating, or spacecraft that are incompatible with the berthing and positioning interfaces. This system should be positionable at a variety of locations using the station manipulator system to accommodate variously sized spacecraft and payloads and to facilitate servicing operations.

Satellite Storage Area

A retention system duplicating Shuttle orbiter payload retention and Flight Support System berthing interfaces should be available for storing retrieved satellites awaiting servicing. Thermal control for the satellite will have to be maintained either through the provision of power to the satellite or through the control of their surroundings.

Station Manipulator System

A station manipulator arm, similar to that existing on the present STS, will be used in support of the following activities:

- Berthing/deploying spacecraft
- Positioning EVA crewman for maintenance activities using the Manipulator Foot Restraint
- Transporting replacement modules to/from the equipment stowage site.

The arm should be long enough to provide access to the module stowage site, to support off-loading of the Space Shuttle and transporting the replacement parts. A second arm may be required to support these functions or more complicated tasks depending on relative locations of the stowage site, Space Shuttle docking port and service center.

A Manipulator Foot Restraint (MFR) work platform should be attached to the arm. This device allows an EVA crewman to be positioned at various locations around the spacecraft being serviced. It also supports the special tooling required for repair/maintenance operations.

Manned Maneuvering Unit (MMU)

An MMU will be used by EVA crewmen to perform berthing operations, transport replacement modules to and from the stowage site, and inspect spacecraft systems.

Resupply Capability

A workstation for recharging spacecraft propellants, pressurants, cryogens, and instrument gases and fluids should be available. Transfer of the fluids could be accomplished by EVA crewmen or automated means within the servicing center. The transfer/recharge system should accommodate the standard fill and drain interfaces on existing spacecraft and future quick disconnect valves on new spacecraft with planned recharge capability.

Stowage Site

Replacement modular systems (instruments or support systems) will be transported to and from the Space Station via the Shuttle. The stowage site should be close to the berthing platform and spacecraft payload retention system to allow the station manipulator arm to be used to transport replacement items. It should be clean, thermally controlled, and unpressurized.

A hardware inventory of standard subsystems (power modules, attitude control system, batteries) should be maintained. Subsystems common to several spacecraft can then be interchanged. Faulty units would be removed and replaced with flight ready units. The faulty units then could be returned to Earth for rework and testing or they can be repaired in the shirtsleeve workshop.

Tool Storage

A tool storage facility within the servicing center would provide ready access to the tooling required to support standard servicing tasks. The tools should include Module Service Tool, power drive, and wrenches required to perform most EVA tasks. Special tooling, unique to a given spacecraft, would be delivered to the Space Station via the Space Shuttle with the replacement item.

EVA Support Equipment

The EVA servicing worksites should be equipped with handrails, slidewires, tethers and foot restraints.

Orbital Maneuvering Vehicle (OMV)

The OMV will be used as the primary mode of capture and transport of co-orbiting free-flyers to the service center docking port. Once docked, the spacecraft will be transferred to the berthing platform or spacecraft and payload retention system for servicing. Servicing may be accomplished on the OMV itself. Precautions must be taken in the Space Station design to minimize the hazard of contamination from the OMV.

Advanced Extravehicular Mobility Unit (EMU)

The EMU is a self-contained spacesuit that provides crewmen with environmental protection, life support, communications, visibility, and mobility during periods of extravehicular activity. An improved EMU system will be required to allow EVA periods of up to 8 hours per day and 40 hours per week without a required day of rest between EVAs. This will result in increased EVA time for servicing or repair activities. Improved mobility and dexterity are key requirements for Space Station era operations.

Shirtsleeve Maintenance Facility (Lab Size)

This section of the Space Station service center should include a contamination-free work environment. The shirtsleeve facility should be attached to the main Space Station elements to permit easy access, without EVA excursion. It will be used to service spacecraft modules, including science instruments.

SPACECRAFT REQUIREMENTS FOR SERVICING

Although the Space Station must satisfy many requirements to fulfill the servicing needs of satellites, each satellite must also meet certain requirements to be serviceable by the Space Station. These design and operation requirements will standardize many aspects of spacecraft servicing as well as ensure the safety of the operations. Standardizing the capture, berthing and maintenance tasks will minimize the servicing time and the necessity for mission-unique servicing hardware. Meeting these requirements will also guarantee that a satellite will be serviceable.

Accessibility is Most Important

The most important requirement, which must be met before any satellite is even considered for servicing, is that the serviceable systems and

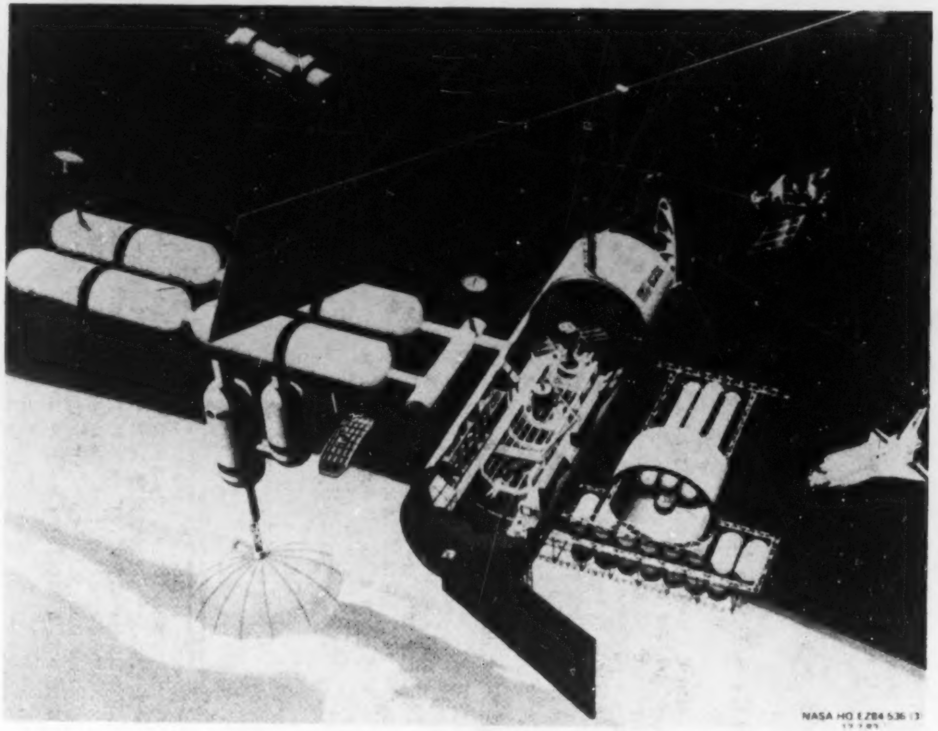

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FIGURE 3.6. FOURTH-ECHELON SERVICING AT THE SPACE STATION

In Echelon Four, an entire spacecraft is brought into a pressurized compartment for servicing.

components be accessible. EVA crewmen will need safe access (body, hand, tool, and visual) to all systems/components that will or may require servicing. Furthermore, the easier access is, the better the chance of successful servicing; EVA time and risk of damaging the satellite or the crew are minimized with easy accessibility. A good example of a system that is easily accessible for replacement is the Modular Attitude Control System (MACS), an MMS module that was replaced during the Solar Maximum Repair Mission. The Main Electronics Box, which was replaced on the same mission even though it was not designed for in-orbit servicing, was able to be replaced due to its accessibility to the EVA crewmen with the use of a few special tools. On the other hand, a satellite that is designed with inaccessible components imbedded within a structure or entangled in harnessing may not benefit from servicing.

Capture, Berthing, and Safing

The first step in servicing a satellite is its capture, which can be accomplished by using the RMS, OMV, OTV, or MMU, depending on the location and dynamics of the target satellite. The spacecraft must have a standard capture interface for the anticipated capture method(s). The standard capture interface would be an RMS grapple fixture if the Shuttle RMS is used to capture the satellite. Standard capture interfaces are not yet defined for the MMU, OTV, and OMV.

After the satellite is captured, it will be berthed onto the Space Station servicing complex, preferably without using EVA. This will require a standard mechanical berthing interface such as that on the MMS Flight Support System (FSS) berthing platform or the Space Shuttle trunnion fitting arrangement. A standard electrical interface between the Space Station and the satellite will also be necessary to supply power to the spacecraft during servicing. Many satellites have appendages such as solar arrays, antennas, and booms that might not allow the spacecraft to fit in the envelope of the servicing center. Depending on their size and orientation, spacecraft appendages will be required to be retractable by motor and with manual EVA backup.

A satellite must not endanger the crew or Space Station during capture, servicing or deployment operations. This requires that any hazardous devices or materials on board, such as propellants, pyrotechnics, radioactive sources, or cryogenics, be efficiently rendered safe without risk to the crew or Space Station. Also, the satellite must be free of sharp edges that could snag or puncture an EVA crew member's suit.

The servicing environment for a satellite will differ from that experienced in its mission orbit and altitude. Sensitive instruments will have to be protected from harmful effects (such as light, gases, etc.) that could be incurred any time during capture and servicing. Auto-actuated protective covers may be necessary for some instruments. In addition, the spacecraft thermal system must have the capability to maintain survival temperatures for all elements of the satellite during each phase of servicing.

Modularity

As already mentioned, each system or component to be serviced must be accessible; the easier access is, the better the chance of successful servicing. In addition, a modular design for serviceable systems and components will ensure that the EVA portion of the servicing can be done efficiently as well as limit the margin for error in handling, connecting, or disconnecting components.

Again, standardization of servicing equipment interfaces will ensure that the Space Station can service the satellite. The satellite must use standard hardware to interface with EVA tools. The standard hardware to be used by all serviceable satellites must be designated and defined. An example of standard hardware is the 7/16-inch hex heads used on the Space Telescope instruments and the EVA interfaces for FSS mechanical overrides. Similarly, standard interfaces for the resupply of liquids for propulsion and cryogenic systems will be required.

Benefits in Ground-Handling

As experienced by the Solar Maximum and Landsat programs during their integration and test cycles, the design of spacecraft for in-orbit repair produces payoffs for ground integration and test cycles. By designing hardware for in-orbit serviceability, ground integration and test cycles have been significantly shortened. In addition, ground troubleshooting is easier by virtue of telemetry formatting for in-orbit remote diagnostic checking.

In essence, if modules and components are designed to be changed out in a 1-hour EVA period, then the same hardware on the ground can be changed out equally as fast. By the same token, if that hardware has been designed to report back any anomalous behavior in-orbit, then the same can be done during ground tests. Finally, if this serviceable hardware and software have been designed to protect themselves against either confused ground instructions or commands or related hardware failures, then the same features will exist on the ground to self-protect the system against test errors or cascading hardware failures.

Summary of Requirements on Spacecraft

In summary, early interface coordination with Space Shuttle and Space Station offices is imperative. Some design and operational requirements imposed on a spacecraft to accommodate servicing at the Space Station are as follows:

- Accessibility of systems/components to be serviced (body, hand, tool, and visual access)

- Standard capture interface--compatible with RMS, OMV, OTV, and/or MMU as necessary
- Standard latch interface for berthing in the service facility
- Standard electrical interface
- Retractable appendages--motor driven with manual override
- Capability to make safe all hazardous systems--cryogenics, hydrazine, pyrotechnics, etc.
- Capability of spacecraft thermal system to maintain survival temperatures for spacecraft elements during servicing
- Protective covers for sensitive instruments that cannot tolerate the servicing environment
- Standard EVA requirements--no sharp corners, standard handrails, etc.
- Standard interfaces for EVA tools
- Standard interface for liquid resupply
- Modular design of systems/components that will be handled by EVA.

Spacecraft Co-orbiting Considerations

Systems that must be kept near the Space Station for servicing or for operations must be designed with careful consideration of orbital drift parameters. As the orbiting spacecraft or platform decreases or increases altitude relative to the Space Station, the precession rate will change relative to the Space Station. This differential precession will result in nodal divergence, requiring large propulsive maneuvers to correct for drift. If frequent servicing or Space Station visits are required, then the spacecraft or platforms must possess sufficient propulsion to stay close to the Space Station node or be prepared to conduct very large propulsive burns to get back to the Space Station.

To rendezvous for servicing, it is not enough for a satellite to have the same inclination as the Space Station; it must have very nearly the same plane. Because the Earth is not a perfect sphere, the planes of all satellites change slightly with each orbit, with planes changing more slowly at higher altitudes. In general, we would like to orbit our astrophysics missions at higher altitudes than the Station, and if we orbit them 150 kilometers higher, their orbits will align with that of the Space Station every 2 years. This is a reasonable interval for servicing, but it has important implications for planning, scheduling, and funding satellite servicing missions. They will become like planetary missions with specific mission windows that appear infrequently. It also means that the Shuttle will remain the primary facility for contingency servicing activities.

CONCLUSION

In summary, the orbital servicing potential of the Space Station represents a significant opportunity for us to increase the return on our spaceflight investments while correspondingly increasing our ability to perform longer and more productive spaceflight missions. This volume attempts to define this capability, while it is yet in the germinal stage, by developing of a set of user and Space Station requirements. Planning at such an early stage will ensure that all potential features are considered, so that future reuse of spaceflight systems will be as commonplace as one-time use is today.

A-1

SATELLITE SERVICING FROM THE SPACE STATION

APPENDIX

Nowhere will the impact of a permanently manned Space Station be felt more than in the servicing of satellites in space. The very idea was made possible by the Space Shuttle and becomes a powerful thrust in the use of space with the advent of a manned base in orbit. This comes at a time when NASA's Astrophysics Program is developing major observatories for investigating the universe from infrared to gamma rays, and after we have repaired our Solar Maximum Mission from the Shuttle. This tremendously successful mission shows just the beginning of what we can expect as the capabilities of the Shuttle develop and the manned base eventually comes into operation.

Already, the Astrophysics Program is planning to use this new capability to assure and extend the lifetimes of future missions. Our four major new observatories--the Hubble Space Telescope, the Gamma Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility--are being designed for servicing on orbit. Other missions can benefit significantly from orbital servicing at the Space Station--in particular, a number of scientific payloads attached to the manned base and whole fleet of small astrophysics free-flyers.

This appendix presents an overview of the types of astrophysics missions--large observatory, manned base, small free-flyer--a brief description of several particular scientific payloads, and a brief consideration of the servicing functions and requirements anticipated for each type of mission. Detailed mission descriptions appear in companion volumes produced by the June 1984 workshop on Astrophysics Utilization of the Space Station.

LARGE OBSERVATORIES

Hubble Space Telescope

The premier space observatory for optical and ultraviolet astronomy will be the Hubble Space Telescope (HST), named for Edwin P. Hubble, the astronomer credited with discovering the awesome size of the universe. The Hubble Space Telescope, planned for launch in 1986, will carry five instruments for ultraviolet and visible light research. It will see seven times further than previous optical telescopes, increasing our survey of the universe to a volume 350 times greater than before, and will photograph in space ten times more sharply than previous telescopes. Sophisticated fine guidance sensors will make astrometric measurements of stellar positions with unexcelled precision to as faint as the 14th magnitude. The present payload is designed for in-orbit replacement and future instruments are expected to include cryogenic infrared sensors. The Hubble Space Telescope is managed by Marshall Space Flight Center, which is also responsible for maintenance and refurbishment; Goddard Space Flight Center is in charge of scientific instruments and mission operations. Hundreds of astronomers will visit the Space Telescope Science Institute in Baltimore, Maryland, each year to perform research with the telescope.

Through quantum leaps in sensitivity and spatial, spectral, and time resolution, the Hubble Space Telescope is expected to make major breakthroughs in fundamental aspects of cosmology, astrophysics, and planetary science. The basic telescope design was driven by the cosmological objectives, which include establishing a definitive distance scale of the universe, reliably estimating the age of the universe, and determining whether the universe is "open" and will expand forever or is "closed" and will eventually halt its expansion to begin a great, perhaps final, collapse that would destroy all the galaxies in space.

The Hubble Space Telescope was designed for in-orbit EVA servicing by Space Shuttle crew. However, this concept is limited to the exchange of a few Orbital Replaceable Units (ORU). Eventually instruments are to be replaced by second-generation, more advanced devices. Servicing at the Space Station in a shirtsleeve environment would allow repair of spacecraft subsystems that are not ORUs or repair of ORUs (such as scientific instruments) for which backups may not be available on a timely basis.

The planned alternative is to return the telescope to the ground for servicing. This is increasingly regarded as unacceptable since return will precipitate serious contamination and affect delicate optical and mechanical adjustments. It is certain that return to the ground would greatly increase the scope, cost, and time of necessary rework. Further, return to the ground is expected to interrupt the scientific program of the telescope for about 2 year's at a time, a prospect viewed with alarm by the astronomy community.

Since the Hubble Space Telescope is already largely constructed, little can be modified now. Thus, the preservation of this $1-billion resource necessarily places requirements on the Space Station for servicing rather than vice versa. In particular, a contamination-free shirtsleeve environment (comparable to a Class 10,000 clean room) is required. Second generation instruments such as two-dimensional spectrographs are expected to greatly increase the data storage and transmission requirements on the telescope. This might mean that spacecraft subsystems not built as ORUs, such as telemetry transmitters, would have to be replaced or upgraded at the Space Station. A Space Station service center could provide the Hubble Space Telescope a logistics base for quick-response maintenance and repair activities to keep the telescope in continuous operation.

Gamma-Ray Observatory (GRO)

Gamma rays are the form of electromagnetic radiation with the shortest wavelengths and the highest energies, and gamma ray astronomy represents a window on many of the most energetic phenomena in the universe. As an example, gamma ray radiation seen from the direction of the center of our galaxy originates from matter-antimatter annihilation, and the time variability of this radiation suggests the presence of a massive black hole at the galactic nucleus. Other sources of cosmic gamma rays include supernovae, pulsars, quasars, and interactions of cosmic rays with matter in interstellar space. Some gamma rays, such as the high-energy radiation from some sources and the low-energy gamma ray bursts, have origins that remain mysterious.

To study gamma rays of all energies and from the whole sky, NASA is developing the Gamma Ray Observatory (GRO), which will do the first complete survey of this high-energy portion of the spectrum. This observatory carries a complement of four instruments.

The Gamma Ray Observatory is being designed with a capability for maintenance and repair either by the Shuttle or at the Space Station. The primary goal of this maintenance is the extension of the life of the observatory beyond its 2-year baseline. Particularly in a field such as gamma ray astronomy where relatively little is already known, an extended mission provides tremendous opportunities for scientific return, such as:

- The study of long-term time variations of sources
- Detailed studies of discoveries made during the initial survey part of the mission
- Deep surveys of extragalactic regions to search for distant objects
- Additional chances to observe rare events such as novae or supernovae.

The key to this extended mission is refueling of the spacecraft, since the low orbit of the Gamma Ray Observatory requires regular reboosting. Additional benefits of servicing are the possibility of repair if a malfunction should occur beyond what is already allowed for by redundancy, replacement of either spacecraft or instrument modules, and perhaps even replacement of an instrument with an upgraded version or a totally new detector concept. This last option would be open to the Gamma Ray Observatory only if the Space Station has relatively sophisticated repair capabilities, since the instruments themselves are not designed for simple replacement.

The Advanced X-Ray Astrophysics Facility (AXAF)

The Advanced X-Ray Astrophysics Facility (AXAF) will study the universe in a unique way, providing x-ray pictures of the farthest reaches of the universe with a depth and detail comparable to those obtained by the most advanced optical and radio telescopes. More importantly, because these pictures will be in x-rays rather than radio waves or visible light, AXAF will provide a new look at the universe.

A vast number of scientific studies can be accomplished only by looking at x-rays. For example, a hot gas at temperatures of millions of degrees fills the space between galaxies comprising the great clusters--groups of hundreds of galaxies bound to each other by the force of gravity. This gas is so hot that it can be observed only in x-rays. Huge amounts of this gas are in the galaxy clusters, and x-ray observations of it map the clusters' gravitational potential. In addition, the mass of the hot gas contributes significantly to the total mass of the clusters and thus to the total mass of the universe.

AXAF will be an x-ray observatory built around a large-area, high-resolution, grazing-incidence x-ray telescope. Designed to operate in space for at least 15 years, AXAF will be operated as a major national facility with the majority of the observing time set aside for guest investigators. This long lifetime will provide the astronomical community with a facility capable of performing the many observations now known to be necessary on the basis of previous investigations and the questions raised by them, and also capable of pursuing, in coordinated observing programs, those new discoveries which AXAF will surely make.

A variety of x-ray instruments can be placed at the focus of the AXAF telescope. Some of these instruments may require consumables for their operation, such as cryogens for solid state devices and gas for proportional counters. These point to the need for in-orbit servicing to minimize downtime and to avoid placing excessive demands on the AXAF spacecraft, such as providing the weight and volume for a 15-year gas supply.

In general, the in-orbit servicing requirements for AXAF fall into three major categories:

- Maintenance of the orbit
- Replenishment of consumables
- Repair and/or replacement of spacecraft and instrument systems or subsystems.

Of these, orbit maintenance is absolutely essential for the long duration (15 years) of the mission. This orbital station-keeping can be achieved with an integral propulsion system, a remotely operated orbital maneuvering vehicle (OMV), or the Space Shuttle. These first two options can be supported from an orbiting Space Station. Various orbital altitude maintenance strategies have been proposed, ranging relatively infrequent reboosts of AXAF from approximately 250 nautical miles to approximately 350 nautical miles every 3 to 5 years to more frequent orbit adjustments of AXAF from approximately 250 nautical miles to approximately 270 nautical miles every 6 to 12 months. Cost trade-off studies are needed in order to evaluate these approaches.

To ease the in-orbit servicing task, the AXAF spacecraft will either be designed to be common to several of the Astrophysics missions, including SIRTF and either HST and GRO, or it will make use of standard Space Station platform modules. This approach will provide a significant degree of commonality between spares, test equipment, and crew training required to support the servicing of astrophysics missions.

The replenishment of consumables is associated mainly with the AXAF scientific instruments. On board gas and cryogen supplies will most likely be limited by size and weight restrictions. The instrument designs must permit replenishment with minimum effort. This might involve fully replaceable subsystems and/or standard fittings and couplings that can be applied to a number of instruments and spacecraft. Co-scheduling replenishment with orbital altitude adjustments reduces the number of servicing activities. However, while orbital adjustments can be entirely remote (OMV or integral propulsion), replenishment will most likely necessitate a rendezvous and an EVA.

The repair or replacement of AXAF components provides a means of recovering from malfunctions of critical systems and for upgrading the observatory capabilities. Similarly, the changeout of instruments for upgrading to newer, more sensitive detectors can be carried out on a scheduled basis, with consolidation of other in-orbit servicing activities. These repair/replacement activities will require a rendezvous with AXAF and an EVA. Advantages of Space Station servicing involve shorter response times to emergencies, simplified service mission planning, and the capability to stockpile parts. The last point is especially true if there are standard units that can be used in several spacecraft flying in similar orbits. These might include power distribution systems, attitude control systems (star cameras and rate gyros), and telemetry systems.

In summary, in-orbit servicing is essential to the success of the AXAF mission, and it is primarily driven by the long lifetime of the observatory. This includes orbital station-keeping, replenishment of consumables, and repair or replacement of AXAF elements. These activities can be carried out via the Space Station, and they have no requirements that are unusual or unique, compared to other observatory-class missions such as the Space Telescope. The development of an orbital altitude strategy appears to be an important driver for in-orbit servicing.

Space Infrared Telescope Facility (SIRTF)

The discoveries of the first infrared survey of the sky, carried out by the IRAS satellite, are just beginning to reach across astrophysical community, and they are showing us things never before seen. The infrared traces the structure and evolution of bodies at temperatures between 10 and 1,000 K. The galaxy is transparent to this radiation, and one is struck by how thin the region of star formation is in our galaxy compared to the stars of the Milky Way seen at night in visible light. (See the maps in Volume 1.) As in other spiral galaxies, most of the bright stars in our galaxy are confined to a disk with the proportions of a long-playing phonograph record. Our view at night is limited to the nearest few hundred light years; if there were no dust, we would be dazzled by the light from stars up to a thousand times farther away, nearly all confined to the narrow plane revealed in the infrared.

Among other discoveries, IRAS found a ring of dust and debris about the star Vega that is likely to be the by-product of the formation of planets. There may be many such stars and debris systems in our galaxy. IRAS appears to have a recorded at least several dozen, but the best instrument for a sensitive search will be the Space Infrared Telescope Facility (SIRTF). It is not enough to see that a star has an infrared excess; the extent and spectral signature of the debris must be resolved to confirm its nature. SIRTF will have at least a factor of 10 times better angular resolution than IRAS, and consequently will provide detailed infrared pictures of even the faintest infrared sources.

Because it operated in space and its telescope was cooled to below 4 K, IRAS had a sensitivity far beyond any previous instrument, and it will not be possible to view the objects in the IRAS survey catalog again until cryogenically-cooled telescopes return to space. SIRTF is a 1-meter class, cryogenically-cooled infrared telescope, designed for long-duration operation in Earth orbit with imaging and spectroscopic instruments. SIRTF will be the most sensitive of all the infrared telescopes planned for the 1990's. Its wavelength range will go beyond the 8 to 120 micron coverage of IRAS to the entire infrared band from 2 to 200 microns. Where they overlap, SIRTF will be 100 to 1000 times more sensitive than IRAS.

The gain in sensitivity of SIRTF over IRAS results from three major differences. First, IRAS was primarily a survey instrument which swept rapidly across the sky, while SIRTF will be a true observatory, carrying a variety of focal plane instruments and capable of extensive observations of a single target. Second, the sensitivity and sophistication of infrared detectors have increased dramatically over the last several years. Some of the SIRTF detectors will be spectrometers providing spectral resolution between 100 to 1000 times greater than the broad "color" resolution of IRAS.

The final difference will be the duration of SIRTF. With resupply of cryogens in orbit and servicing of other subsystems, it is entirely reasonable to design SIRTF for a 10- or 15-year mission. This will allow the astronomical community maximum utilization of the tremendous capability provided by SIRTF. While replacing and upgrading the scientific instruments within SIRTF is desirable, this capability will be difficult because the entire telescope is cryogenically cooled. These servicing activities may only be possible with a Space Station facility.

ATTACHED PAYLOADS ON THE MANNED BASE

The Space Station can be used as a mounting platform and service center for externally attached astrophysics payloads. Because it provides long-term stability, a relatively low contamination environment, a large mass-support capacity, and ready access for servicing, the Space Station is well-suited as a base for large instruments requiring long-duration operations and periodic maintenance.

Instruments for research in two astrophysics disciplines--solar physics and cosmic ray physics--have been identified as candidate attached payloads. Servicing these payloads primarily will involve frequent replenishment of consumables (at about 6-month intervals) and occasional instrument change-out to upgrade a facility.

To study fundamental physical processes on the Sun, solar physicists desire simultaneous, long-term observations over the entire electromagnetic spectrum. Such research requires an ensemble of instruments making coordinated observations within different spatial, spectral, and temporal parameters. The Space Station is a good platform for a solar instrument complement pointed at the same target of observation. It also can support expansion of the complement, by instrument changeout, into a larger, more mature observatory facility. The Advanced Solar Observatory (ASO) will develop on the Space Station in this evolutionary fashion from the Solar Optical Telescope and the Pinhole Occulter Facility.

Precise investigations in cosmic ray physics require long observation periods, very large detectors, and stable pointing away from Earth. The flux of cosmic rays near Earth is of great interest, since these high-energy charged particles contain information about their sources, the interstellar medium, and the acceleration processes that enable them to travel vast distances through space. The manned base provides not only a suitable place to mount very large cosmic ray instruments but also a facility for changing their configurations, resupplying consumables, and retrieving exposed materials on a timely basis. The Transition Radiation Ionization Calorimeter (TRIC) investigation, a modified version of the Spacelab Cosmic Ray Nuclei Experiment, probably will be the first attached payload in the discipline of cosmic ray physics to use the Space Station's capabilities.

A-8

WORKSHOP ON

ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on

Servicing Astrophysics Missions at the Space Station

Mr. B. Ronald McCullar, Chairman

Mr. Michael Bay
Mr. Richard Cable
Mr. Frank Cepollina
Dr. John Dickey
Mr. Ronald R. Felice
Ms. Jean C. Folse
Mr. Kevin J. Grady
Mr. Joseph P. Loftus, Jr.
Mr. Francis J. Logan
Mr. David R. Manges
Dr. Stephen P. Maran
Mr. James Murphy
Dr. Stephen S. Murray
Dr. Valerie Neal
Mr. Ed Pruett
Dr. Philip Schwartz
Dr. David R. Soderblom
Mr. Lewis Sprott
Mr. James Steincamp
Dr. David E. Thompson
Mr. Howard F. Trucks

ASTROPHYSICS AND THE SPACE STATION

VOLUME 4

ASSEMBLING ASTROPHYSICS MISSIONS AT THE SPACE STATION

A major advance in our ability to study and understand our universe was achieved when we were able to place astrophysical telescopes and instruments in space, above the obscuring presence of earth's atmosphere. The advent of the Space Shuttle offered new capabilities for carrying astrophysical payloads into orbit. The Hubble Space Telescope, for example, was sized to make optimal usage of the Space Shuttle's carrying capabilities.

The Space Station era will open even broader vistas for such astrophysical observations. No longer will the sophistication and performance of spaceborne instrumentation be limited by weight and volume constraints imposed by the carrier vehicle. In-orbit assembly and construction will eventually make achievable and practical spaceborne observatories many times the size that can be accommodated by the Space Shuttle. Already, the need for a Large Deployable Reflector (LDR) more than 10 meters in diameter has been identified by the National Academy of Sciences as the major orbiting observatory for submillimeter astronomy. Such large observatories will advance present capabilities by orders of magnitude, making possible observations across the electromagnetic spectrum that will penetrate to the very edges of the universe with both high spatial and spectral detail. In-orbit assembly and construction is expected to be an evolving capability of the Space Station. The likely evolutionary stages of the Space Station capabilities will include servicing (e.g., monitoring and material change-out, maintenance and repair), payload checkout and integration to orbital maneuvering or transfer vehicles, and assembly and construction. Without the Space Station, many of these operations will be costlier, less productive, or simply impossible. Once the Space Station servicing capability is mature, in-orbit assembly becomes a logical step of capability.

To provide an early perspective on astrophysics requirements for in-orbit assembly in conjunction with the Space Station, four missions have been selected as being representative of the range of astrophysics missions that will require such assembly: the Large Deployable Reflector (LDR), the Coherent Optical System of Modular Imaging Collectors (COSMIC), the High Energy Space Station Array (HESS Array), and the Gamma Ray Imaging Telescope System (GRITS). The success of these missions will depend critically upon a Space Station that includes in-space, in-orbit assembly facilities by the end of the 1990's. This volume describes the hardware and objectives of the missions and develops assembly scenarios for the hardware.

LARGE DEPLOYABLE REFLECTOR (LDR)

The Large Deployable Reflector (LDR), planned for the late 1990's, is an observatory to observe electromagnetic wavelengths in the submillimeter and far infrared range. It will be placed in a low Earth orbit that will permit the LDR to operate over a portion of the electromagnetic spectrum (30 to 1000 microns) that is completely obscured by the Earth's atmosphere. The LDR will have to be at least 20 meters in diameter to achieve the angular resolution needed for many of LDR's most important scientific investigations at these wavelengths. Because these dimensions exceed the capabilities of the Shuttle bay, and because the projected mass for the system may exceed the Shuttle capacity, the LDR must be either folded to fit into the Shuttle bay or transported with more than one Shuttle launch for subsequent assembly in orbit.

Figure 4.1 is an artist's rendering of the Large Deployable Reflector. The present concept is a Cassegrain system (with the focus behind the primary mirror), with a pri~~mary ref~~lector having a focal length equal to its diameter. This design is straightforward and has minimal optical aberrations over a narrow field of view. The science instrument package and focal plane assembly are located behind the vertex of the primary reflector to maximize the structural rigidity.

LDR Size Requirements

The size of LDR is driven by requirements for angular resolution and instrument sensitivity. One of LDR's main scientific problems will be to investigate the cold, dense regions of dust and molecular gas where stars are formed. These regions are highly structured, leading some stars to form in orbiting pairs and some to form planets. How? To find out, we will have to observe with sufficient angular resolution to discern the structure and with sufficient sensitivity to determine the state of the molecular gas, its excitation, density, magnetic fields, and velocity throughout the region.

A good illustration can be made with Figure 4.2, the Whirlpool Nebula, a nearby galaxy with a pronounced spiral structure connected in a suggestive way to a smaller companion galaxy. With the angular resolution of this picture, about 1 second of arc, we can see that the bright regions of the spiral arms are right next to some very dark lanes of dust that completely absorb the light from the stars as they form. We suppose that our own galaxy is a spiral like this, only not so striking. The only way we can investigate the overall pattern in a spiral galaxy is to get a top view as shown; the results help us interpret what we observe about our own galaxy from the inside.

While the resolution of the picture in Figure 4.2 is good, it is easy to see that to learn about the events inside the dust lanes, we have to have the capability for angular resolution at least this good. For LDR, this means a telescope diameter of 20 meters.

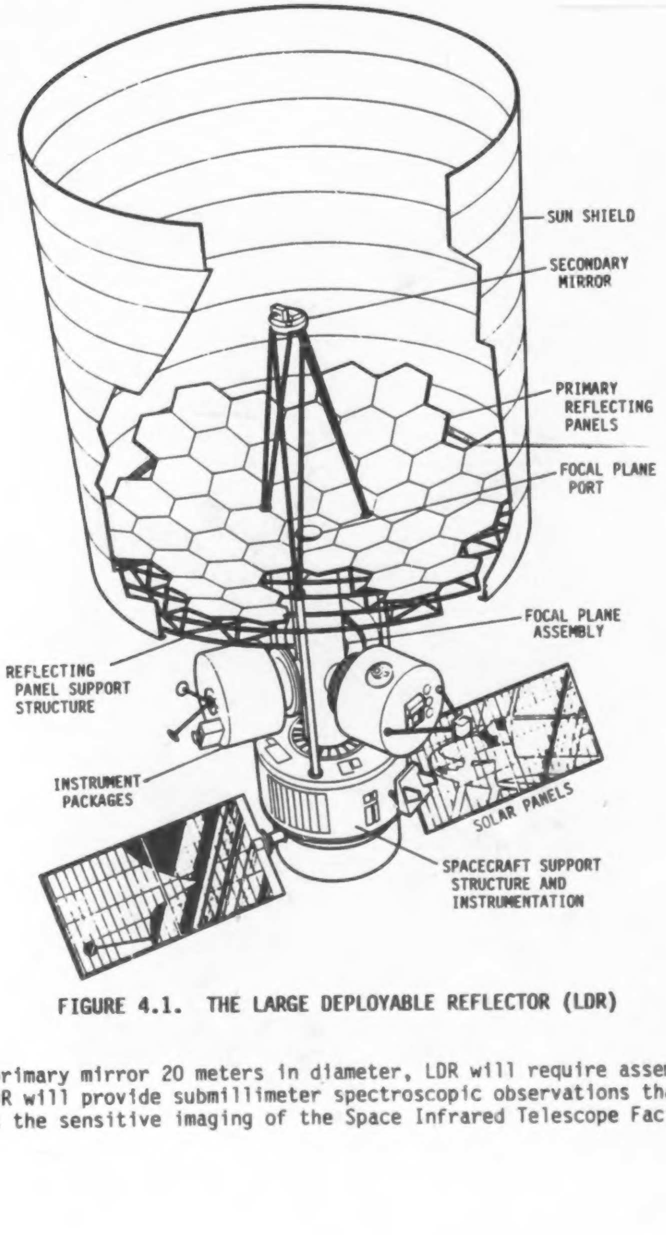
SUN SHIELD
SECONDARY MIRROR
PRIMARY REFLECTING PANELS
FOCAL PLANE PORT
FOCAL PLANE ASSEMBLY
REFLECTING PANEL SUPPORT STRUCTURE
INSTRUMENT PACKAGES
SOLAR PANELS
SPACECRAFT SUPPORT STRUCTURE AND INSTRUMENTATION

FIGURE 4.1. THE LARGE DEPLOYABLE REFLECTOR (LDR)

With its primary mirror 20 meters in diameter, LDR will require assembly in space. LDR will provide submillimeter spectroscopic observations that will complement the sensitive imaging of the Space Infrared Telescope Facility (SIRTF).

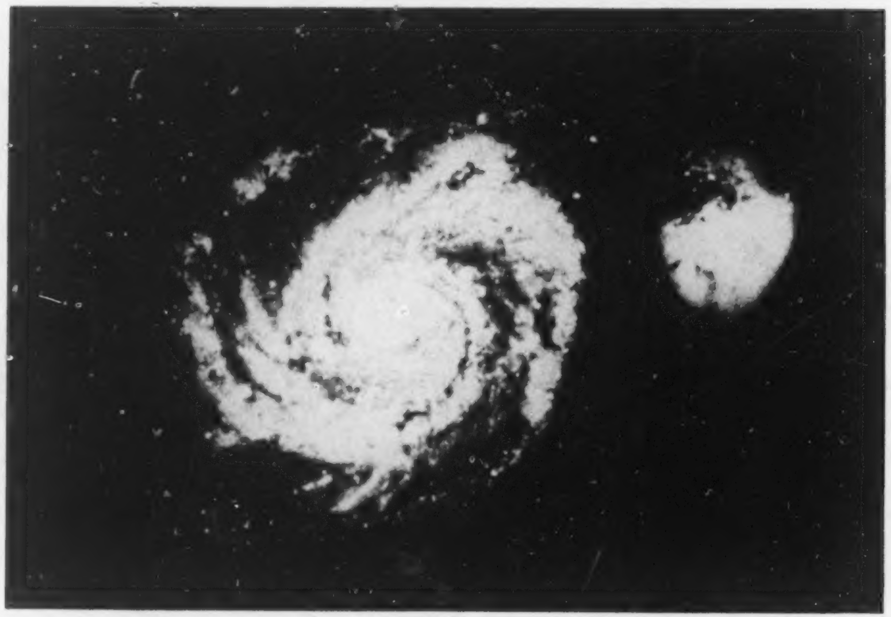

FIGURE 4.2. THE WHIRLPOOL NEBULA (M-51)

The resolution of this picture is approximately 1 arcsecond. LDR must be large to resolve the formation of stars.

Equally important for LDR is high sensitivity. Molecules radiate at discrete frequencies that uniquely identify the molecule and its state of excitation. The velocity of the gas is typically a few hundred meters per second, causing a shift of only one part per million in the frequency we observe. While LDR will have this spectral resolution and more, it is clear that if we divide the radiation into a million frequency channels, tremendous light-gathering power is needed to make up the sensitivity lost in the division by the spectrometer.

A National Academy of Science Recognized Need

It is the significant scientific content of infrared and submillimeter astronomy that compels us to find a way to develop LDR. Star formation is thought to proceed in a cascading chain of events, starting as interstellar winds and shock waves (that we are far from understanding) sweep up gas from the space between the stars and collect it into giant molecular clouds. The process continues with the collapse of the clouds and the formation of dense disks out of which stars and planets finally form.

This is the theory, in any case, and it predicts that the best way to investigate the physical process of birth in astrophysics will be in the submillimeter and infrared wavelengths. This is recorded in the recommendation of the Astronomy Survey Committee of the National Academy of Science report Astronomy and Astrophysics for the 1980's. It ranked LDR as one of the four major new observatories recommended for development in this decade.

Spectroscopic LDR Complements Imaging SIRTF

The temperature of the telescope does not matter so much at high spectral resolution. The radiation of the heat from LDR's mirror will be divided into more than a million channels of frequency as we examine the narrow bands of emission from molecules rotating and vibrating in response to forces in interstellar space. In each channel, the background will be very low.

For sensitive imaging, however, as much radiation as can be gathered from the source has to be put into a single wide channel. In sensitive imaging SIRTF will excel with its telescope cooled to within a few degrees of absolute zero. This low temperature allowed IRAS to make the first far infrared maps of the sky in its pioneering mission. Even with a primary mirror only 1 meter in diameter. SIRTF will be more sensitive than LDR for many investigations of quasars and active galaxies, dust surrounding stars in birth and stars near death, and the small particles around stars like Vega that are clearly related (in a way we do not yet know) to the formation of planets.

Structure and Assembly of the LDR

The reflecting surface will consist of individual panels mounted on a rigid structure with actuators to adjust the individual panels in orbit. Because of the limited size of the Shuttle cargo bay, the panels will be limited to a 4-meter crosswise dimension. The technical requirements for the LDR include the following:

- Primary mirror diameter of 20 meters
- Primary mirror made up of 20-200 individual rigid panels supported by a truss backup structure
- Panels of 1-3 meters in diameter
- Instrument package mounted behind vertex of reflector
- Eight focal-plane instruments requiring 3-4 cubic meters total volume
- Total system mass of 25,000-50,000 kilograms
- Instrument cooling to temperatures of 1-100 K required
- Reflector cooled passively to 150-200 K
- Orbital altitude of 700 kilometers
- Fifteen-year orbital lifetime, with periodic revisits to the station for instrument and cryogenic replacement
- Thermal shade 22 meters in diameter and 25-30 meters in length required
- Optical surfaces protected from contamination
- 5-10 kilowatt power.

One possible assembly scenario for LDR calls for preassembling portions of the primary reflector truss with the actuators and reflector panels attached. These preassembled modules would be sized to fit in the Shuttle cargo bay. Once delivered to the Space Station, the modules would be stored until all the modules have been delivered. The assembly facilities would then be used to take the individual modules and connect them. Other LDR systems would similarly be broken down into pieces that would easily fit in the Shuttle and then be assembled at the Station. This scenario would allow efficient packaging in the Shuttle and would eliminate the cost of developing expensive deployment mechanisms.

Another possible assembly technique--one that more fully exploits the Space Station capability--is one that uses an Assembly and Transport

Vehicle (ATV). With a trusswork platform in a low-contamination area of the Space Station, the construction would begin by attaching a module containing the focal-plane instruments and various other observatory instruments to the Space Station by means of a support structure that would permit the instrument module to pivot about its centerline. The astronauts would construct the primary mirror by assembling the support structure in sections and attaching control actuators and hexagonal mirror facets to the substructure as each section is completed. The pivoting instrument module would permit the astronauts to assemble the mirror with only simple, moderate movement of the manipulator arms of the ATV. After the primary mirror was in place, the sunshade would be partially assembled around the hexagonal primary mirror; the support structure for the secondary reflector would then be erected. The remaining portions of the sunshade would then be assembled completing the construction of the LDR. The system would be checked out with the LDR still attached to the Space Station. After checkout, an Orbiting Maneuvering Vehicle would be attached to the LDR, and the observatory would be propelled into a higher orbit.

Construction of the LDR at the Space Station would relieve many of the design constraints that would apply if the LDR had to be designed to be transportable in a single Shuttle flight.

COHERENT OPTICAL SYSTEM OF MODULAR IMAGING COLLECTORS (COSMIC)

In its most studied configuration, COSMIC is an array of eight telescopes along a system structure 36 meters long and 4 meters in diameter. Like the Large Deployable Reflector, it is driven to large size to gain angular resolution and sensitivity--this time in visible and ultraviolet light. Unlike LDR, COSMIC uses an array of telescopes as an interferometer.

To understand this difference, we start with a familiar imaging system. LDR's aperture will be completely filled with mirror panels except for a small hole at the center to let the infrared and submillimeter radiation back to the instruments. The hole is small and has no effect on the resolution of the image formed on the instruments; if the hole were made larger, the only effect would be to make the image fainter.

COSMIC carries this to an extreme, deleting almost all of the mirror panels to form an array of telescopes connected by a precise optical system, as illustrated in Figure 4.3. By combining the light from the telescopes along paths that are kept equal, COSMIC achieves all the angular resolution of a telescope 36 meters in diameter, but only in the long dimension of the array. The full performance of a telescope 36 meters in diameter is synthesized by rotating COSMIC about the line of sight.

COSMIC Size Requirements

Currently, the sharpest pictures we have of any objects come from arrays of radio telescopes ganged together like the optical telescopes of

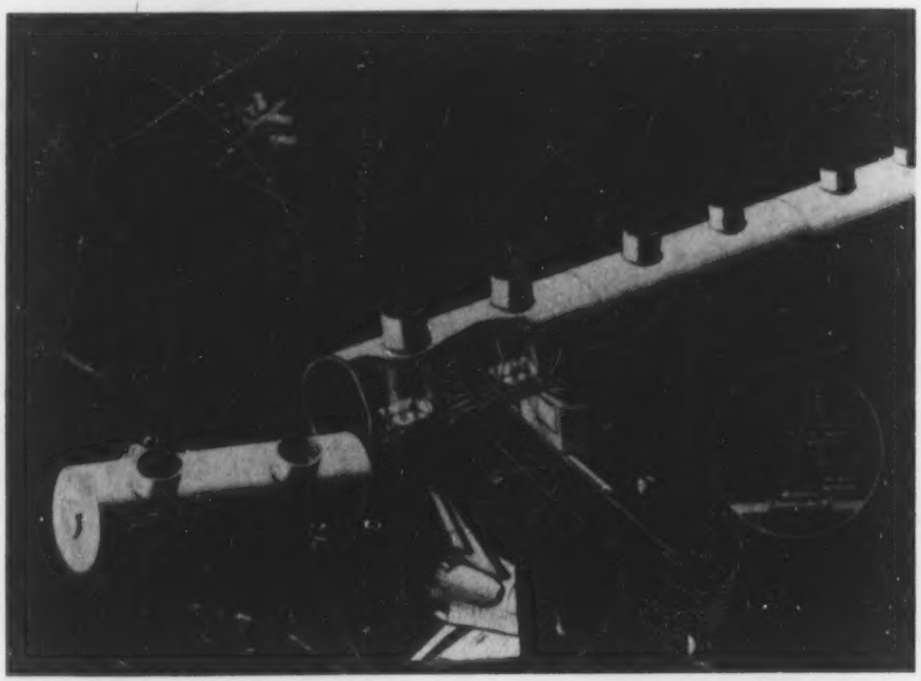

FIGURE 4.3. COHERENT OPTICAL SYSTEM OF MODULAR IMAGING COLLECTORS (COSMIC)

Space assembly is also required for this system, which will give the angular resolution of a visible-light telescope 36 meters in diameter.

COSMIC. While the best ground-based optical images are typically smeared to be no sharper than 1 arc-second by the twinkling we see in stars, by combining the signals in radio telescopes on opposite sides of the world, images a thousand times sharper have been obtained. What they have seen is a universe in constant motion, illustrated in Figure 4.4. There, a blob of luminous material is ejected from the central core of the quasar 3C 273. What is especially remarkable about these images is that the blob appears to move away from the quasar at a little over the speed of light.

But what is the blob? What can it tell us about the quasar that ejected it? Figure 4.4 shows the emission at radio wavelengths which are sensitive to very energetic electrons in magnetic fields, but quasars also emit visible and ultraviolet light in the discrete frequencies of highly excited atoms. Are they excited as the blob goes by? Are they part of the blob? These spectral lines contain a wealth of information, but we need to know how they are excited before we can interpret them. There appears to be no way to find out without achieving, in visible light, the resolution comparable to that in Figure 4.4. We will need a 36-meter interferometer to distinguish the blob from the quasar.

The image resolution and sensitivity of COSMIC would also be used to investigate the surfaces of nearby supergiant stars. On some of these stars, the advanced stages of nuclear combustion have turned the outer layers into giant, boiling masses of gas. Images of these surfaces are expected to show complex, exaggerated motions that may reveal a better understanding of the structure of all stars, including the Sun.

COSMIC will also be used to study contact binary stars that orbit each other so closely that they almost touch. In these objects, gas from one star is pulled off by the gravity of its companion to produce a complex atmosphere governed by gravitation, radiation, kinetic energy, and magnetic fields. Until now, what is known about these objects has been learned from their spectra; with COSMIC, the flow could be observed directly and examined over time to ascertain the specific effects of these forces.

In our own solar system, the surfaces of Pluto and its recently discovered moon Charon could be surveyed, and COSMIC would be used to image the rings of Saturn with resolution similar to that achieved by Voyager. In addition, COSMIC could provide a detailed look at the nuclei of comets to observe their activity as heat from the Sun drives surface material into the comet's coma and tail. Finally, we expect to be able to learn a great deal about the "solar wind" by using COSMIC.

Structure and Assembly of COSMIC

The design concept of COSMIC has been optimized for transport on the Space Shuttle. It is composed of modules 18 meters long and 4 meters in diameter, containing all optical systems fully assembled. These modules would completely fill the Shuttle bay and would be joined together as they are brought up. Mechanical, electrical, and optical connections would then be made, and optical alignment and telemetry systems would be checked out.

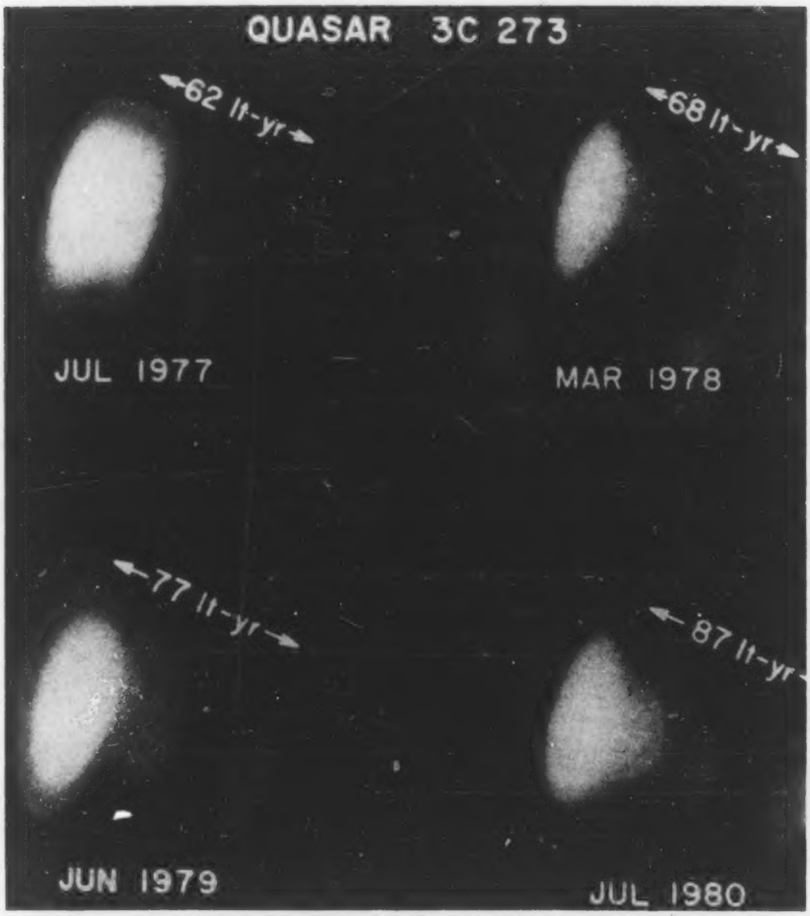
QUASAR 3C 273
62 lt-yr
68 lt-yr
JUL 1977
MAR 1978
77 lt-yr
87 lt-yr
JUN 1979
JUL 1980

FIGURE 4.4. RELATIVISTIC EJECTION OF MATTER FROM QUASAR 3C 273

The motion of the blob of relativistic electrons appears to exceed the speed of light. COSMIC must be very large in order to resolve distances of tens of light-years in such sources as 3C 273, whose distance from Earth is about 15 percent of the distance across the entire universe.

Many of the fine or critical adjustments may exceed 1 week and thus would not be possible if the Space Shuttle alone were involved; they would require an extended stay at the Space Station. Such activities would include coarse-alignment verification, thermal stablity checks, and verification of mechanisms, as well as structural position adjustments to fine-tune the optical alignment.

Being manned, the Space Station could provide better opportunities and greater flexibility in activities such as attaching additional solar panels, opening and extending of Sun shades, replacing aging components (such as gyros, electronics, and batteries), replenishing expendables (such as gas for control jets), and refurbishing the focal-plane instrumentation. Furthermore, the prospect of space assembly permits entirely new packaging concepts that promise greatly reduced costs. A good example is the erection of light shade baffles which may be assembled without regard to conventional launch-load design requirements, thereby lowering cost through reduced structural load requirements.

The COSMIC concept has evolved based on the Space Shuttle as the assembly and transportation system. With the development of the Space Station as a permanent, manned facility in space, many of the limitations of volume, weight, and orbital staytime imposed by the Shuttle have been removed.

HIGH ENERGY SPACE STATION ARRAY (HESS ARRAY)

The Space Station will make possible a mission to obtain the spectrum and composition of the rarest and most energetic cosmic rays. The central portion of HESS Array is a massive set of detectors assembled from 256 identical modules, each measuring 16 centimeters by 16 centimeters by 2.5 meters. Each module contains a thick layer of a solid scintillating material and a thin tungsten layer. The scintillator produces a signal proportional to the amount of ionization caused by the cosmic ray particles, and the tungsten provides additional stopping power. The stacked modules form the calorimeter, a cube approximately 2.5 meters on a side capable of measuring the energy of cosmic rays incident from any direction.

Between each layer of 16 modules, there is room for a tray of passive detectors for studying nuclear interactions of these extremely energetic cosmic rays. Figure 4.5 shows the modules stacked to form the body of the calorimeter.

Since the central body of the calorimeter is not capable by itself of identifying the incident particles, the exterior surfaces of the calorimeter cube will be covered with charge-sensitive detectors. A 4 x 4 module array would be used to cover each surface of the calorimeter except the bottom. These modules could be mounted on a hinged frame which could be swung out of the way when access to the calorimeter modules was desired.

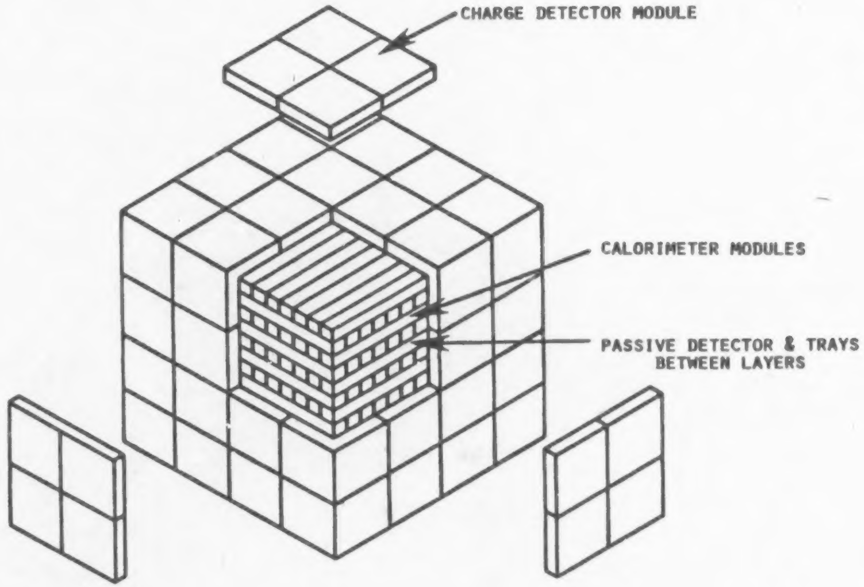
CHARGE DETECTOR MODULE
CALORIMETER MODULES
PASSIVE DETECTOR & TRAYS BETWEEN LAYERS

FIGURE 4.5. HIGH ENERGY SPACE STATION ARRAY (HESS ARRAY)

The large size and great mass of the HESS Array are needed to observe extremely rare and energetic cosmic rays that carry an important signature of their acceleration.

HESS Array Size Requirement: Stopping Cosmic Rays

The High Energy Space Station Array (HESS Array) mission is not too large to fit into the Shuttle bay whole, but it is far too massive to be lifted whole by the Shuttle. This mass is needed to stop cosmic rays, which have energies greater than 10^{16} electron volts (eV). Electron volts are a convenient measure of energy for nuclear particles because these particles typically have only one or at most a few times the charge of an electron, so we know that they have been accelerated through a potential of about 10^{16} volts before arriving at earth.

This is not to say that a single immense electric field in interstellar space accelerates the cosmic rays. Probably, the acceleration occurs in many small, random steps to produce the distribution we observe with many more cosmic rays at lower energies than at higher energies. The oldest question in high energy astrophysics, in fact, concerns how cosmic rays get their enormous energies.

The answer appears to be held at the highest energies--the energies that HESS Array is designed to observe. One reason that HESS Array is so large is that particles with this much energy can transmit their energy far into massive objects they encounter.

The cosmic rays themselves do not travel beyond their first nuclear collisions, but in that collision they can generate dozens of secondary particles, many of them exotic and highly unstable, which go on until their first nuclear collision to produce another generation of particles--each parent sharing its energy with the particles of the next generation in a cascading shower that only ends when all the energy has been dissipated in the ionization of the calorimeter's counters.

HESS Array Size Requirement: Rarity of Cosmic Rays

The cascading shower of energy also develops in the atmosphere, and arrays of detectors on the ground have observed showers that must have been generated by particles having as much 10^{21} electron volts. For perspective, note that 10^{21} eV is one Joule (the energy needed to lift one gram more than one meter) contained in a single atomic nucleus arriving at the Earth. The energies of 10^{13} to 10^{16} of interest for HESS Array are also quite large, especially when compared to the energy contained in the mass of the particle, $E=mc^2$. For a proton, the nucleus of a hydrogen atom, this energy is just about 10^9 eV--completely negligible compared to the energy expended accelerating the particles to velocities so close to the speed of light.

However, the more energetic the cosmic rays, the rarer they are. HESS Array is scaled to be large enough to observe a critical reduction ("bend") in the distribution of cosmic rays that occurs at about 10^{15} eV. It is the composition of the cosmic rays, the number of protons in the nucleus, that will tell us whether shock waves, generated by supernova explosions traveling in low-density regions of hot interstellar gas, are primarily responsible for accelerating the cosmic rays.

This current theory incorporates elements of several earlier theories--energy from supernovae and acceleration in the interstellar medium. It is important to note that the best theory of 5 years ago, that cosmic rays come directly from supernova explosions, failed to predict the composition observed by cosmic ray instruments on the third High Energy Astronomy Observatory (HEAO-3).

In the current theory, the efficiency of acceleration breaks down when interstellar magnetic fields can no longer contain the cosmic rays close to the shock front, and the energy where this occurs depends on the charge and on the mass. There will be a characteristic signature in the composition at these energies, if the current theory is right.

The following table shows the expected number of events observed by HESS Array above various threshold energies in 2 years of operation at the Space Station.

The numbers in the table are adequate to provide a definitive picture for our understanding of the acceleration mechanism, and they will enable us to reach the energy at which a break in the spectrum is expected and to tell, by comparing the energy at which the break occurs for protons and helium nucliei, what type of mechanism is operating to produce it.

EXPECTED NUMBER OF EVENTS TO BE OBSERVED
ABOVE THRESHOLD IN TWO YEARS

	Threshold Total Energy (eV/Nucleus)		
Particle Type	10^{14}	10^{15}	10^{16}
Hydrogen	50,000	1.000	20
Helium	26,000	5,200	10
Carbon, oxygen	11,000	220	4
Neon, magnesium, silicon	8,400	170	3
Iron	13,000	260	5

Structure and Assembly of HESS Array

Assembling HESS Array in orbit will be much simpler than assembling LDR or COSMIC. Each 100-kilogram module will be designed as a self-contained unit, completely checked out on the ground. With a flexible packaging concept, the modules could be brought to the Station on Shuttle launches whenever space is available. Each module would be fitted with guidepins and simple latches so that when it was removed from the crate, it could be snapped into place in a lightweight holding fixture on the Space Station. Each module would be hooked onto the previous one as the crates were unloaded, eliminating the need for intermediate storage facilities. Modules would then be plugged into support electronics attached to the mounting frame. By the time several layers of the detector were in place, data-taking could begin.

As currently envisioned, HESS Array will need 16 square meters of Space Station structure with a clear, continuous view of space. It will also need 1000 Watts of power, 100 kbits/sec downlink telemetry, assembly and servicing capability, and temporary storage. The storage area would have to be maintained at about 20 C and have a volume of approximately 20 x 20 x 300 centimeters to accommodate a locker for the target material. The expected mission lifetime includes 1 to 2 years for construction and 5 to 10 years for operation.

GAMMA RAY IMAGING TELESCOPE SYSTEM (GRITS)

The Gamma Ray Imaging Telescope System (GRITS) will observe gamma rays with energies of more than 100 MeV. When gamma rays of this very high energy get close to the nucleus of an atom, they can convert virtually all their energy into an electron and an anti-electron pair moving at nearly the speed of light. The pair also goes in very nearly the same direction as the incoming gamma ray and the main components of GRITS will work to measure the direction of flight of the particle-antiparticle pair.

As presently conceived, GRITS will use an expended Shuttle External Tank as its basic structure. Behind a thin target for converting the gamma rays into pairs, an external tank will be filled with pressurized gas. Light travelling through the gas does not go quite as fast as light in a vacuum. For GRITS, the gas used will have a pressure such that the electrons and anti-electrons will be travelling faster than the speed of light in the gas. The result will be like a jet that breaks the sound barrier. Light will be given off in a trail behind the particles, reflected in a mirror at the rear of GRITS, and observed with sensors at the front of the telescope to determine the direction of flight.

Primary Mission of GRITS

Like cosmic rays, the higher the energy of the gamma rays, the fewer there are to observe, and because there are very few gamma rays at energies greater than 100 MeV, very large detectors must be used to locate the sources in a reasonable period of time. Even larger detectors are needed to be able to find out when more (or fewer) gamma rays are arriving.

In many cases this variability in number carries the significant information about a source. The pulsar in the Crab Nebula has a rotational period of only 33 milliseconds--so short that only a neutron star could remain

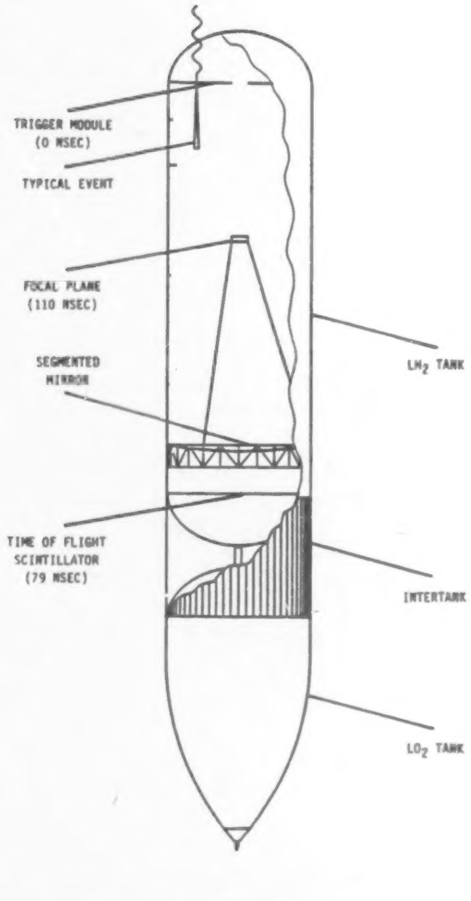
TRIGGER MODULE
(0 NSEC)
TYPICAL EVENT
FOCAL PLANE
(110 NSEC)
SEGMENTED
MIRROR
TIME OF FLIGHT
SCINTILLATOR
(79 NSEC)
LH2 TANK
INTERTANK
LO2 TANK

FIGURE 4.6. GAMMA RAY IMAGING TELESCOPE SYSTEM (GRITS)

Although very high energy gamma rays are rare, they provide essential information about the most energetic objects in the universe. GRITS uses a Shuttle external tank to hold its large-area sensing system.

intact at such a rapid rotation rate. This pulsar has been observed to pulse in x-rays, visible light, and gamma rays, all with the same period. For each of these types of radiation, the pulses appear at precisely the same time during the period. In the case of the gamma rays, however, the brightness of the second pulse has been gradually declining while the first pulse has remained constant. GRITS will be able to tell us what is happening in this very unusual object. At very high energy levels (above 2,000 MeV), gamma rays are so energetic that they do not need the strong electric field of an atomic nucleus to create electrons and antielectrons; they can create pairs in the magnetic field of the pulsar. Small changes in the strength of the field will have a large effect in the intensity of the gamma-ray pulses. GRITS will need to be very large if it is to determine variations in the number of very-high-energy gamma rays.

Structure and Assembly of GRITS

The external tank would be prepared on the ground with special fittings of a meteoroid shield and an aluminum lattice support structure for the segmented mirror. The tank would be carried along with the Shuttle to the Space Station. With the telescope and subsystem components being carried in the payload bay, all the necessary components would be delivered in one Shuttle flight.

Two assembly methods are possible. In the first, the entire inner apparatus can be installed during extravehicular activity. In the second, a docking adapter can be built into the tank; a tunnel could then be connected to the pressurized portion of the Space Station, and the tank could be reconfigured in a "shirtsleeve" environment.

Because structural strength is not critical in weightless conditions, the inner instrumentation can be attached by Velcro or push pins to a thin sheet stretched across the interior of the tank. Likewise, the mirror segments can be installed with lightweight snaps, and the tank can then be sealed and pressurized. Spacecraft subsystems can be installed on the inside or outside of the tank to make it an autonomous, free-flying observatory.

SPACE STATION REQUIREMENTS

In space construction, there will always be a major trade-off decision between automatic deployment and man-assisted assembly. At one extreme is the automatic deployment of a folded structure. The expanded structural size is then limited by the ingenuity used in packaging the structure and by the cargo capacity of the Shuttle; in this case, the deployment mechanisms must be extremely reliable, and the requirement for efficient packaging leads to complex joint designs, limited truss member lengths, and strut components with hinge breaks. In contrast, erectable structures are easier to pack, and although they take more steps to construct in space, the structure will be stronger. In addition, astronauts will be available to take corrective actions during assembly. Because erectable structures generally can be expected to be stiffer, greater geometrical precision is possible and less active control is needed to maintain the structural shape. For this reason, erectable structures are favored for astrophysics applications, in which optical alignments are critical.

Because of its permanent, manned status, the Space Station would be an ideal base for manpower and resources to construct these missions in space. Although the Shuttle could provide the same services, its limited stay-time in orbit could not provide the manpower, time, or resources that would be required for space assembly of these astrophysics missions spacecraft.

Following is a set of general requirements that the Space Station must meet if it is to handle the assembly scenarios described earlier. However, these missions are far enough in the future that they can be adapted to many possible changes in the Space Station's design. These requirements are merely an attempt to define standard accommodation capabilities for the Space Station. Space Station assembly capabilities are applicable not only to sophisticated missions like LDR, COSMIC, HESS Array, and GRITS but also to the assembly of much simpler payloads, such as those described in Volume 5.

Assembly and Storage Areas

Space must be adequate for assembling large payloads and temporarily storing parts and partially finished structures that are awaiting completion. The general requirement is for space outside the Station, but the possibility of assembly in a "shirtsleeve" environment is very desirable. Initially, this pressurized volume may be part of a Space Station module, but later a large workspace, 20-30 meters in diameter, could prove to be efficient and cost-effective for large assembly missions. Any internal assembly workspace will have to allow for the transfer of assemblies that are nearly as large as the workspace itself.

Standard Interfaces and Resources

The mission equipment interfaces to the Space Station for data, fluids, power, thermal connections, and communications should be standardized to Space Station systems. Standard interfaces will make the Space Station more adaptable, as more and more payloads will use them.

Mobility

The Space Station must provide a means to transport and manipulate crew, material, and equipment around the assembly area. A vehicle could be attached to an assembly boom structure and provided with manipulators. For example, some Space Station plans include an Assembly and Transport Vehicle (ATV), a movable platform to be used in construction and to extend and maintain the Station. The vehicle would be attached to the Space Station truss structure and would let the astronauts move around fairly freely during extravehicular activity to move Station modules, modify structure and components, and perform maintenance. The ATV will be tremendously valuable for in-orbit construction of astrophysics missions like LDR, COSMIC, and HESS Array.

A space crane attached to the vehicle would be used for positioning payloads while the astronauts work on them. As robotics increase in sophistication, mobile assembly devices can evolve to a fully teleoperated system, leading to increased productivity in construction and servicing in space.

Storage and Docking Facilities

The Space Station must have the capability to move large items from the Shuttle and provide storage space for them until assembly. At least one storage facility should be able to accommodate an item, such as a spacecraft, that completely fills the Shuttle bay.

EVA Capability

There must be a capability for extended extravehicular activity with high mobility and the capability to use special tools and test equipment in space.

Lighting and Power

Lighting must be provided so that assembly would not be restricted or determined by orbital position or time. The Space Station may also have to provide power and cooling for the payloads being assembled, during their test and checkout periods. Manipulating equipment and operating assembly tools will also require electrical power.

Environment

The Space Station environment must not contaminate the paylods. Consequently, the Space Station must be able to isolate payloads from such things as volatiles that may corrode or condense on optics, electromagnetic interference, and vibration. Although many payloads can adapt to variations in the Space Station's environment, the Station's external assembly space should be as far as possible from major contamination sources.

Orbital Transportation Services

The Space Station must be able to provide transportation for large payloads (25,000-50,000 kilograms) to higher orbits at low acceleration. These transportation services must also be able to retrieve and deliver assemblies to near-station orbits as required.

SUMMARY

As has been seen in this volume, the Space Station will be an essential part of the future of astrophysics. The capabilities provided by the Station for assembling large structures in space will allow for efficiencies in design that are not possible with the Space Shuttle alone. Missions such as COSMIC, with its lengthy and critical optical alignment requirements, could not be accomplished without the extended stay time that would be provided by the Space Station. The LDR, which requires a great deal of volume in the Shuttle's cargo bay and repeated trips before it can be usable, will be more efficiently assembled in space at the Space Station. Other missions, such as the HESS Array, could not be economically accomplished without the Space Station as they have a mass larger than a single Shuttle flight could carry into orbit. The Space Station is therefore a needed capability for the advancement of astrophysics.

WORKSHOP ON

ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on

Assembly of Astrophysics Missions at the Space Station

Mr. Micheal Kiya, Chairman
Dr. Paul A. Cooper
Mr. Thomas M. Crabb
Mr. Maurice Dubin
Dr. Kenneth Frost
Dr. Daniel Gezari
Mr. James Grady
Dr. Herbert Gursky
Mr. Peter Jones
Mr. Max Nein
Mr. R. Bruce Pittman
Mr. Fred Shepphird
Dr. Kandy Shivanandan
Mr. Thomas Sisk
Mr. Gene E. Stone
Dr. Robert Streitmatter
Dr. Paul N. Swanson
Dr. Wesley A. Traub
Mr. Alan B. Wissinger

ASTROPHYSICS AND THE SPACE STATION

VOLUME 5

SPACE PLATFORMS FOR ASTROPHYSICS

In the first four volumes of this report, we described how the Space Station can be used as an observation base, as a servicing center, and as an assembly base for astrophysics missions. In this last volume, we describe how the Space Station may lead to a new generation of spacecraft for our missions and how they might be used. The new generation we call "space platforms". They are likely to come in a spectrum of sizes to accommodate a spectrum of missions, and they are characterized by their long lives--made possible by the Space Station.

Nearly every astrophysics mission is a candidate for a "space platform" of some type, because only a very few missions require orbits that are incompatible with the Space Station. Our flagships are our great observatories; however, with the Space Station, it makes sense to develop sustained spacecraft, space platforms, for Explorer missions and perhaps even small, developmental missions.

This volume begins with a discussion of the new generation of spacecraft, describes technical aspects of spacecraft systems that may become part of future platforms, and ends with a set of scientifically important missions that are best accommodated on these platforms.

(Editor's Note: At the Workshop on Astrophysics Utilization of the Space Station, discussion focused on moderate and smaller, Explorer-class missions, their scientific importance, and the impact of the Space Station on their implementation. Results from the Panel on Space Platforms for Astrophysics, emphasizing these missions, are the main subject of this report. Since the Workshop, new and significant information has been developed on Space Station platforms and how they might be used for NASA's program of major, orbiting observatories, and we are including the new results because of the relevance to the work by the panel. We have reviewed the new information with members of the scientific community and have incorporated the information in a special section, "Space Station Platforms for AXAF and SIRTF.")

NEW GENERATION OF SPACECRAFT

When the Shuttle was under development, it was clear that we were acquiring a new resource for servicing spacecraft in orbit, and it made sense to begin developing spacecraft that could be maintained and updated. This could only be done for a facility important enough to justify the servicing, and at the same time, being serviceable and having a long operational lifetime justified the expense of a major observatory. The convergence of servicing capability and scientific need defined the observatories of the Shuttle generation, and none better than the Hubble Space Telescope (HST) with its orbital replacement units (ORUs) for both focal-plane instruments and spacecraft subsystems. In the same generation are the Gamma Ray Observatory (GRO) and the smaller solar physics platform that carries the Solar Maximum Mission (SMM).

Space Station and Long-Lived Spacecraft

It is a general engineering principle that for a complex system to endure, it must be designed to be fixed. A key design feature highlighted during the repair of SMM is that accessibility is the most important factor governing whether a subsystem can be repaired in orbit. From this principle, a system of servicing echelons has been defined and is described for the first time in Volume 3 of this report.

We have not designed before truly long-lived spacecraft following these principles. Our enduring planetary missions are beyond our reach, and the closest we have come before the Space Station has been to plan for replacing some modules in orbit and scheduling major overhauls on the ground. Now, with the Space Station on the horizon, NASA has decided to do all the servicing of HST in orbit; studies have shown that this is possible even though HST was not originally designed for complete independence from ground servicing. For the Space Station generation of astrophysics observatories--the Advanced X-Ray Astrophysics Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF)--accessibility and modularity will be the baseline: they will be designed from the beginning for complete independence from ground servicing.

The Space Station is just as essential for the viability of smaller platforms as it is for observatories. The possibility of using the Station as a transportation node solves an important problem that has inhibited investment in permanent, orbiting facilities for a series of payloads like the Explorers: it is very difficult to schedule a Shuttle launch to rendezvous with a spacecraft for a small payload. Small payloads must share launches with others, and finding payloads with compatible orbital requirements is very difficult. The transportation and storage facilities of the Space Station make it possible for private companies to begin investing in space platform services that can be leased to payloads.

The general requirements for serviceability are given in Volume 3, but key points for a discussion of platforms are:

- Design everything so that it is accessible
- Obtain the required orbital transfer capability
- Design platforms for total compatibility with the Station.

SPACE STATION PLATFORMS FOR AXAF AND SIRTF

Requirement for Long Life

It is the scientific importance and versatility of the major observatories and their complementary capabilities that lead to the requirement of mission lifetime measured in decades. HST, AXAF, and SIRTF together essentially cover the spectrum from the far infrared through x-rays, and as long as GRO remains operational, we will have coverage through gamma rays. Many of the most important problems we know about, including the source of power in quasars and the radiation mechanisms of pulsars, require multispectral observations to determine what is going on, and it is long life that makes the multispectral capability possible while maintaining the traditional, few-year separation between starts of major observatories.

In addition, AXAF, SIRTF, and HST will provide high quality images of cosmic sources in x-rays, infrared, visible, and ultraviolet light to a set of instruments that are very sensitive, powerful, and, for the most part, capable of being replaced with even more powerful instruments. These three observatories will not become obsolete for many decades. Although GRO will not last that long, its primary objective is to perform a sensitive survey of the sky at all gamma-ray wavelengths, and its data base will extend coverage of all objects to the highest energies.

The great orbiting observatories can be compared to the observatories on the ground which have not become obsolete because instrumentation has made such great advances. But there is another reason: we are in a time of great discovery as we observe the universe. Astrophysical investigations are finding one or two entirely new, major phenomena each year, and although this rate of discovery cannot continue indefinitely, we do not see any decline yet. When we attempt to estimate how much there is left to discover, we find that we may be aware of less than half of the major phenomena that will be studied by astronomers over the next fifty years.

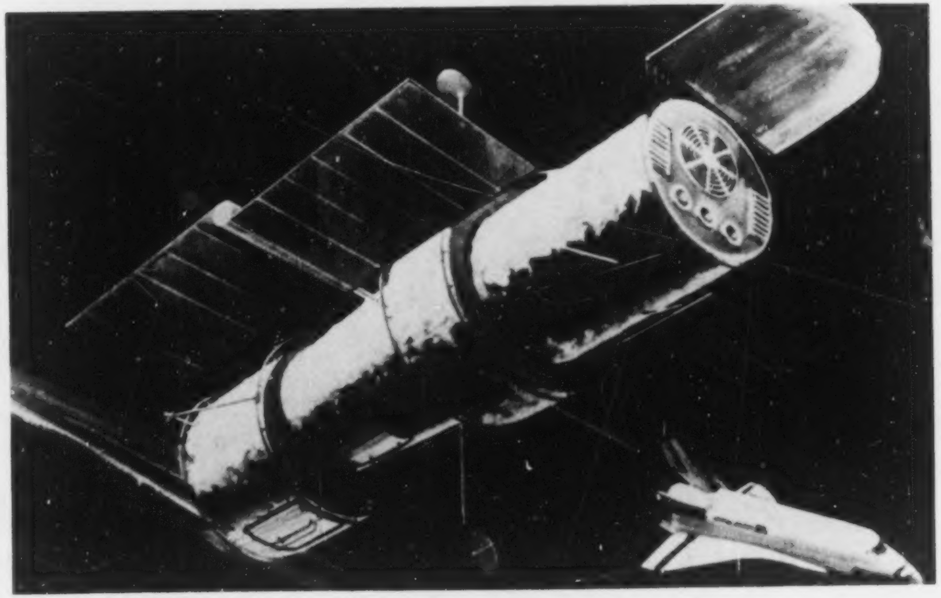

FIGURE 5.1. THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)

AXAF will be as significant an advance in x-ray astronomy as the Hubble Space Telescope is for visible and ultraviolet astronomy. Launch of AXAF is planned for the early 1990's.

Attributes of AXAF and SIRTF Platforms

With our definition of platforms as sustained spacecraft, our requirement for decades of mission life for the AXAF and SIRTF spacecraft makes them space platforms. Concepts for SIRTF and AXAF are going to be judged on the life-cycle costs for 10 and 15 years of operation.

The modular approach has already been proven with SMM, GRO, and HST and is expected to be more important for AXAF and SIRTF. Because AXAF and SIRTF have such similar requirements, we expect that the modules could be common to both missions. As part of this approach, the modules should:

- Use Space Station protocols and standards in the command and data handling subsystem so that the communications interface with the Space Station during servicing will conform with the Space Station standards.
- Use Space Station standards in the power and thermal subsystem to integrate with the Space Station interface during servicing.
- Use Space Station standards for attitude and spacecraft control so that capture, manipulation, and berthing will be common with other Space Station systems.
- Be able to fit through the Space Station airlock so that they can be serviced at the component level in a pressurized environment (Echelon-3 servicing).

Other technical requirements for AXAF and SIRTF are given in Table 5.1 and compared with HST.

The great observatories will become true "space platforms" of the space station era when AXAF and SIRTF meet these requirements and provided that the Space Station has an airlock large enough to accommodate the entry of HST modules. The coming generations of spacecraft and instrument modules for HST and the other great observatories are being designed to be serviced in the shirtsleeve environment.

PLATFORMS FOR MODERATE AND EXPLORER MISSIONS

Astrophysics missions with considerably less complexity than AXAF and SIRTF can be accommodated by a number of concepts. Among these are dedicated and multiuser platforms that would be available from the government or private sector.

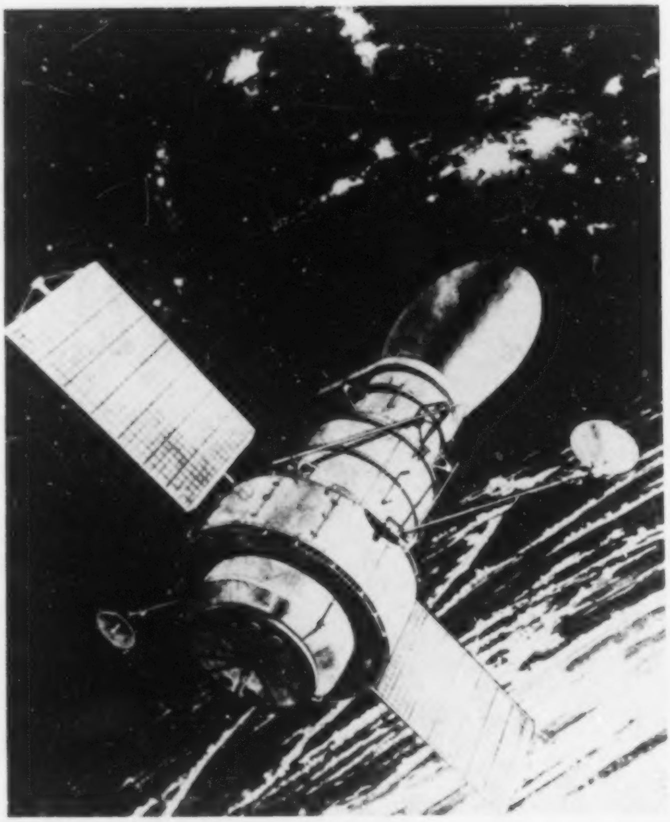

FIGURE 5.2. THE SPACE INFRARED TELESCOPE FACILITY (SIRTF)

This cryogenically-cooled observatory will be the major observatory for infrared astronomy.

TABLE 5.1. COMPARISON OF KEY TECHNICAL REQUIREMENTS FOR AXAF, SIRTF, AND HST

Parameter	AXAF	SIRTF	HST
Launch Year	1992*	1993*	1986
Mission Duration (yrs)	15	10	15
Launch Mass (kg)	10,000	7,250	11,600
Power (W)	1200 (regulated)	1859	2500
Pointing Accuracy (arcsec)	30	0.15	0.01
Pointing Stability	0.5 (for 10 sec)	0.10	0.007 (for 12 hrs)
Data Rates	48 kbps (science) 16 kbps (eng)	300 kbps	1024 kbps (telescope)
TDRSS (Data Transmission) Services**			
Forward	125 bps (MA) or 1 kbps (SA)	<10 kbps	125 bps or 1 kbps (SA or MA)
Return	512 kbps (SA)	<3Mbps (SA) or 50 kbps (MA)	1Mbps (SA)

* For planning purposes only

**SA = Single access
MA = Multiple access

Multimission Modular Spacecraft (MMS)

The MMS is a standard spacecraft bus designed to incorporate standard modular subsystems which provide power regulation, energy storage, attitude control, propulsion, and communication and data handling functions for a wide range of experimental or operational space missions. The MMS can also be adapted to accept mission unique items that are compatible with its multiplex-data bus. The MMS provides autonomous operation through the use of an onboard computer, which is capable of performing such tasks as attitude control, ephemeris computation, stored command processing, power management, thermal control, and payload operations. Spacecraft communications are accomplished through both the NASA Ground/Space Tracking and Data Network (GSTDN) and the Tracking and Data Relay Satellite System (TDRSS).

The MMS is designed to be fully compatible with both expendable launch vehicles and the NASA Space Transportation System (STS). The STS compatibility is accomplished through the use of the MMS Flight Support System, which was designed and built for use in conjunction with the Shuttle orbiter for the on-orbit servicing of MMS type satellites. MMS spacecraft are presently in operation on the Solar Maximum Mission observatory and on both the Landsat-4 and Landsat-5 earth observation satellites.

With the dawn of the satellite servicing era, the MMS modular design becomes even more important to the payload user. Servicing capabilities incorporated in the MMS design provide the user with the ability to repair, replace, or resupply a satellite from either the NASA Space Station or the operational Space Transportation System. The ability to service an MMS type satellite was successfully demonstrated with the replacement of the Modular Attitude Control Subsystem during the Solar Maximum Repair Mission. This was accomplished as part of mission 41-C on the Space Shuttle Challenger. Figure 5.3 illustrates the modular design of the MMS.

Leased Services

A leased-service platform would provide flight opportunities in low Earth orbit for scientific, commercial, and government users on a leased or service-contract basis. The platform would employ standard modules for electrical power, communications and data handling, and attitude control, with additional modules being used to increase power, to achieve greater system accuracy and controllability, or to carry additional, smaller payloads. Systems such as these would be unmanned and initially Shuttle-tended until Space Station services would be available.

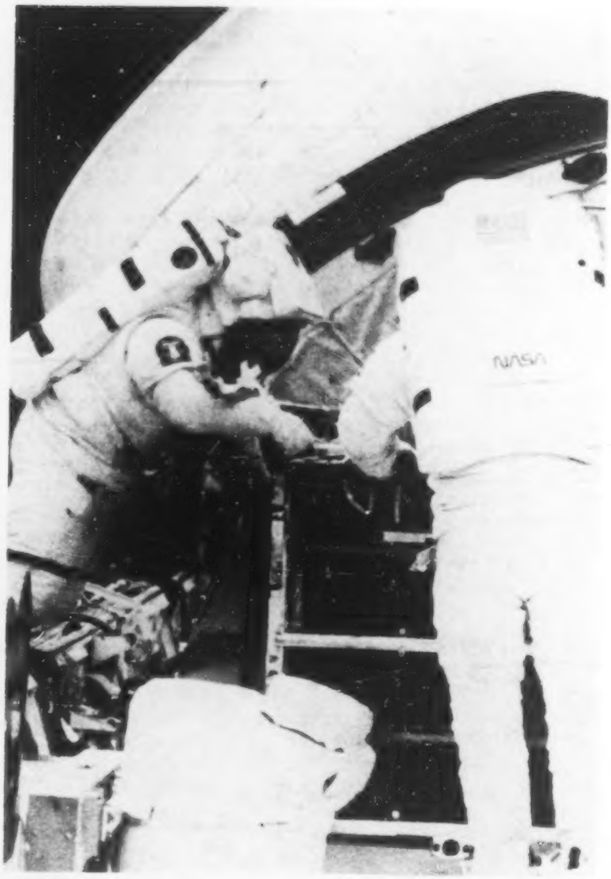

FIGURE 5.3. MODULAR DESIGN OF THE MULTIMISSION MODULAR SPACECRAFT

Astronauts install the Attitude Control Subsystem Module in the Solar Maximum Mission.

Proteus

The Proteus concept, currently being studied at GSFC, would be an autonomous spacecraft that provides full support to a variety of science investigations. It would have the propulsive capability, either integral or with an OMV, to leave the Space Station orbit and return at mission's end. The system configuration of the spacecraft would be a Shuttle-launched, modular, space-serviceable bus with the pointing flexibility of stellar-inertial, reaction wheel attitude control. Direct TDRSS links would allow complete independence from the Space Station between servicing visits. The anticipated spacecraft life would be greater than 10 years. This long life would be achievable through the repair and enhancement opportunities of a space-serviced modular design.

The significant, unique feature of Proteus is its attention to the interface between scientist and system at all levels: hardware, communication, data handling, software, and management. Transparency of the system is a prime Proteus development target. Principal Investigators would receive hardware that interfaces with the spacecraft, eliminating the need for interface design. Packetized data telemetry would permit each observer to customize data format and content for the individual experiment. Ground Service Equipment (GSE), like the spacecraft, would be modular and employ standard interfaces to enhance flexibility and adaptability.

PLATFORMS FOR EXPERIMENTS OF OPPORTUNITY

Often, new concepts for astrophysics instruments involve new technology to achieve higher sensitivity or higher resolution, and before the instrument can be approved for use in major observatories or other missions, it must be tested in space. Today, these opportunities are provided through NASA's suborbital program, carrying instruments in the top of the atmosphere and beyond with airplanes, balloons, sounding rockets, and Spartan carriers. New and important scientific knowledge usually results from these test flights, and during the Space Station era, it will be critical that opportunities continue to be made available to test new instrument concepts in space. We expect that the Space Station will make some of these opportunities possible.

Space Station Spartans

A Spartan-class carrier would provide the capability of orbiting small payloads for brief periods (less than a week to as much as a month) at very low cost. Based on the Shuttle Spartan concept, the Space Station version would operate out of the Station, co-orbiting in the immediate vicinity. Among the main differences from the Shuttle version would be a quick-disconnect payload interface, improved serviceability, and rechargeable batteries.

A Space Station Spartan would be an autonomous spacecraft that could co-orbit with the Space Station for periods up to a month. For electrical power, it would employ batteries but no solar arrays. With no communications link, data would be collected and stored on a large (10 Gigabit) tape recorder, using a programmable, fixed-format multiplexer. Operational control would be achieved with stored commands, and attitude would be controlled by a three-axis cold gas thruster assembly, using stellar-inertial (star tracker and gyros) sensors and microprocessors for control. Sun or Earth sensors are readily accommodated. No propulsion capability is planned, so the Space Station would have to provide deployment and retrieval support.

Payload modules for the Spartan would be delivered to the Space Station in the Shuttle orbiter. Each payload would be equipped with its unique "game cartridge" that controls pointing, power switching, data handling, and other mission-unique computer functions. As soon as the payload is attached to the Spartan via the standard interface, the game cartridge would be inserted, the batteries charged, the cold gas tanks filled, the tape recorder rewound, and a functional check-out performed. The Spartan would then be deployed for a few days in orbit. When Spartan is retrieved, the payload would be removed and returned to Earth. The observed data would be returned through the Space Station communications link.

CANDIDATE MISSIONS

We now discuss the candidates for platform-based moderate and Explorer class missions by scientific discipline rather than by system size and complexity. The objectives, current status, and intended mode of operation of each mission will be presented.

High-Energy Astrophysics

The following section describes several high-energy astrophysics missions that are well suited for operation on space platforms. The missions were selected as representative examples of usage of platforms in the context of the Space Station system, and no prioritization of missions is implied.

X-Ray Timing Explorer (XTE)

Fundamental physical information about neutron stars and black holes is contained in the dramatic changes in x-ray luminosity that occur in the brightest cosmic x-ray sources. Indeed, the discovery of periodic x-ray pulsations in a few sources was the key to their identification as neutron stars.

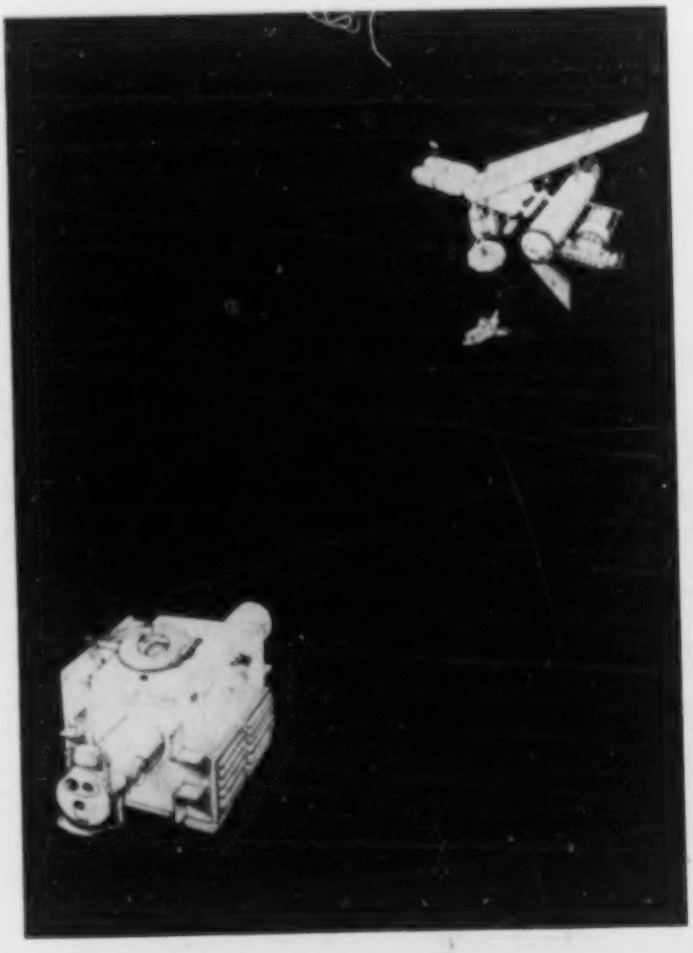

FIGURE 5.4. A SPACE STATION SPARTAN

Monitoring of the pulsations revealed Doppler shifts of the pulse period and, in a few cases, periodic eclipse-like disappearances of the X-ray source. These timing data were the critical information that revealed the true nature of the sources--binary star systems with mass from a normal star flowing onto a collapsed, compact companion star.

Black holes and neutron stars have the mass of an entire star within a radius of only 1 to 10 km. X-rays are produced in copious amounts as accreting matter is funneled and accelerated in their intense gravitational fields. Changes in their x-ray emission have been a rich channel of information for determining the fundamental properties of x-ray sources. The X-ray Timing Explorer (XTE) will provide the means to carry out detailed investigations of compact x-ray sources.

Mission Instruments. Three instruments have been selected for use in the XTE mission. Two of these, the Large Area Proportional Counter Array (LAPC) and the High Energy X-ray Timing Experiment (HEXTE), will study individual objects over long periods of time. The third, the Scanning Shadow Camera (SSC), will monitor the whole sky to alert the other instruments to the onset of unusual events that could be observed. The SSC will also accumulate, from its hourly samples, records of the behavior of the 200 brightest sources over the duration of the mission.

The instruments will have timing resolution of about 10 microseconds and will be ideal for measuring the energetic environments in X-ray sources. They will also be sensitive to features in the stellar spectra which indicate the magnetic and thermodynamic conditions in these sources.

Status. In 1985, we will choose among candidate spacecraft systems to carry XTE, ranging from an integrated free-flyer to a platform dedicated to the XTE mission. XTE has also been considered for the first mission to use the Proteus concept; its requirements are typical of the free-flying specialized missions that have high priority in NASA's astrophysics program.

XTE is being defined for launch in the early 1990's. It will be launched with the Shuttle and integrated with its platform in the Shuttle bay before it begins its 2-year mission. De-integration of XTE is likely to be one of the first platform tasks conducted at the Space Station as the platform is prepared for its second mission.

Operations. The scientific operations of the XTE mission will be conducted at the Goddard Space Flight Center in accordance with a scientific program determined by the Principal Investigators for each instrument and by Guest Investigators from around the world. In its primary mode of operation, XTE will point at a target for times ranging from 1 hour to several weeks. The LAPC will observe the target with high time resolution and low spectral resolution (15 percent at 6 keV) over the 2-60 keV range while HEXTE will

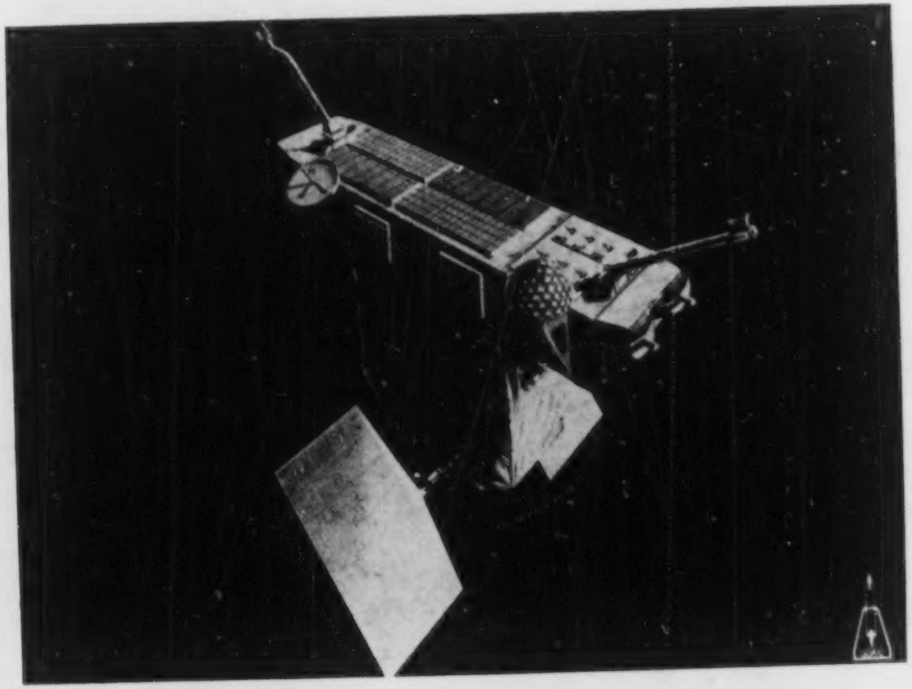

FIGURE 5.5. THE X-RAY TIMING EXPLORER

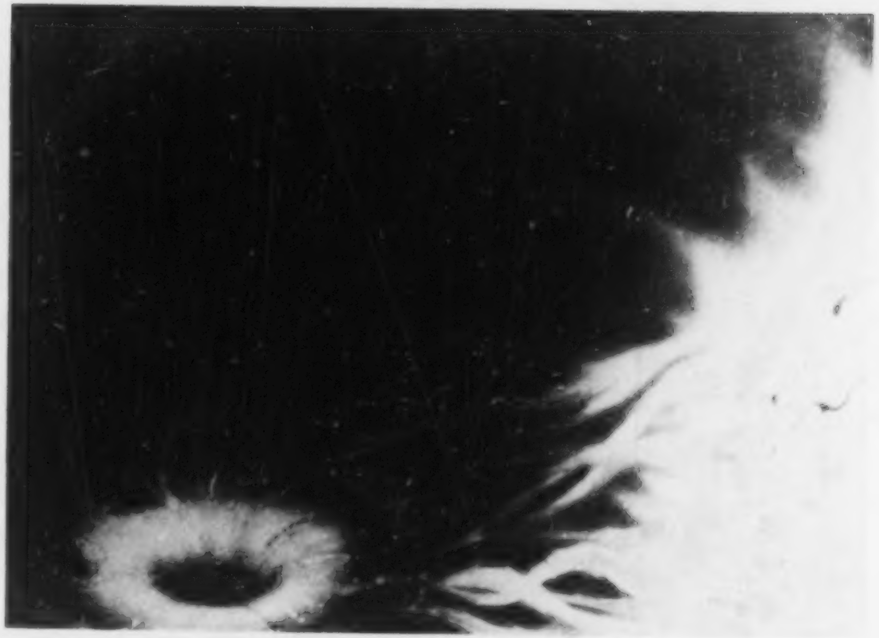

FIGURE 5.6 ARTIST'S CONCEPTION OF MATTER FLOWING FROM A NORMAL STAR INTO A BLACK HOLE, PRODUCING X-RAYS

alternate between viewing the target and viewing a nearby background region. SSC will scan the sky for new, transient sources and monitor the brightest sources.

High-Energy-Transient Explorer (HETE)

HETE is a candidate mission proposed to carry out a comprehensive, all-sky, broad-band study of a special class of short-lived but very bright cosmic X-ray and gamma-ray sources. These are called high-energy transient sources, and their behavior has defied our understanding: How an object that normally cannot be detected can suddenly outshine the entire universe in x-ray or gamma ray emissions and then vanish in a matter of seconds is very difficult to understand. This is a significant area of investigation in the study of high-energy astrophysical phenomena, because these sources are a critical probe of fundamental physics under extreme conditions.

Mission Instruments. High-energy transient sources are difficult to observe in detail and require specialized instruments to determine important physical parameters like temperature, density, and magnetic field strength right from the onset of the burst. To obtain this information, the HETE scientific payload will most probably consist of three instruments making measurements in the X-ray, gamma-ray, and optical bands. The instruments are:

- All-Sky X-Ray Camera

  The primary objectives of the All-Sky X-Ray Camera are to determine the location of gamma-ray and X-ray bursters very accurately and to measure the time histories and energy spectra of X-ray and gamma-ray bursts in the X-ray band. Using coded aperture imaging or grazing-incidence optics, the instrument will be expected to be able to view at least half the sky. It will be required to have enough sensitivity to detect a 10-second transient event over a range of energies.

- Spectrometer

  The spectrometer will measure transient-event spectra in the hard X-ray and gamma-ray range, from 10 keV to 10 Mev. With a field of view that nearly fills the field of the All-Sky X-Ray Camera, the spectrometer will be surrounded by an active scintillator shield to suppress background from the spacecraft. Its other specific requirements are yet to be determined.

- Optical Transient Camera

  The Optical Transient Camera will be able to detect the optical transients that are likely to accompany gamma-ray bursts, and it will cover the same field of view as the All-Sky X-Ray Camera and the Spectrometer. The Optical Transient Camera will require enough sensitivity to detect a very low-energy event lasting only 1 second.

Status. The modest requirements of the HETE complement of instruments fit well within Proteus's capabilities. For data analysis, the pointing direction will have to be known accurately, although the imaging instruments will be able to self-calibrate on known bright X-ray and optical sources. Because of the relative rarity of these transient events, it should be possible to maintain a fairly low data-transmission rate (~30 kbps).

This mission would be integrated at the Space Station with a platform having at least the capabilities of Proteus. It would be brought to the Station by the Shuttle and possibly stored in orbit until the platform could rendezvous with the Station for de-integration and re-integration for its mission as HETE.

Operations. After it is transferred to its orbit, HETE would begin scanning the zenith around its orbit. When an x-ray or gamma-ray transient occurs, data on its location, its x-ray intensity profile, and its gamma-ray intensity profile would be stored along with accumulated spectra and optical information. At first, these data would be telemetered at a low rate, but after a year of operation, the system would be programmed to transmit an alarm message with essential information for action from other observatories, possibly including observatories on the Space Station.

If high-resolution, cryogen-cooled detectors are part of the payload complement, periodic (6 months - 1 year) replenishment of the cryogen will be necessary. The servicing capabilities of the Space Station should be ideally suited for carrying out this task.

High Throughput Mission (HTM)

HTM is an x-ray astrophysics facility in the moderate-mission class that will complement other x-ray observatories by having low angular resolution but very large collecting area. HTM will address scientific objectives that do not require very high resolution but for which sensitivity is crucial.

Mission Instruments. High sensitivity is needed to observe the regions of million-degree gas in our galaxy that are heated by supernova explosions and by stupendous winds from very young, massive stars. These regions are the major source of hydrodynamic pressure that sweeps up gas and dust in interstellar space to form the next generation of stars. High sensitivity is also needed to observe million-degree gas in coronae around nearby galaxies and in the immense regions of intergalactic space in clusters of galaxies. The distribution, composition, and temperature structure of this gas will reflect the dynamical history and evolution of the galaxies since they were formed.

To achieve high sensitivity for these faint, extended objects, up to 100 grazing-incidence x-ray telescopes will be grouped together, side by side, to provide an effective collecting area of 1 square meter or more. (In

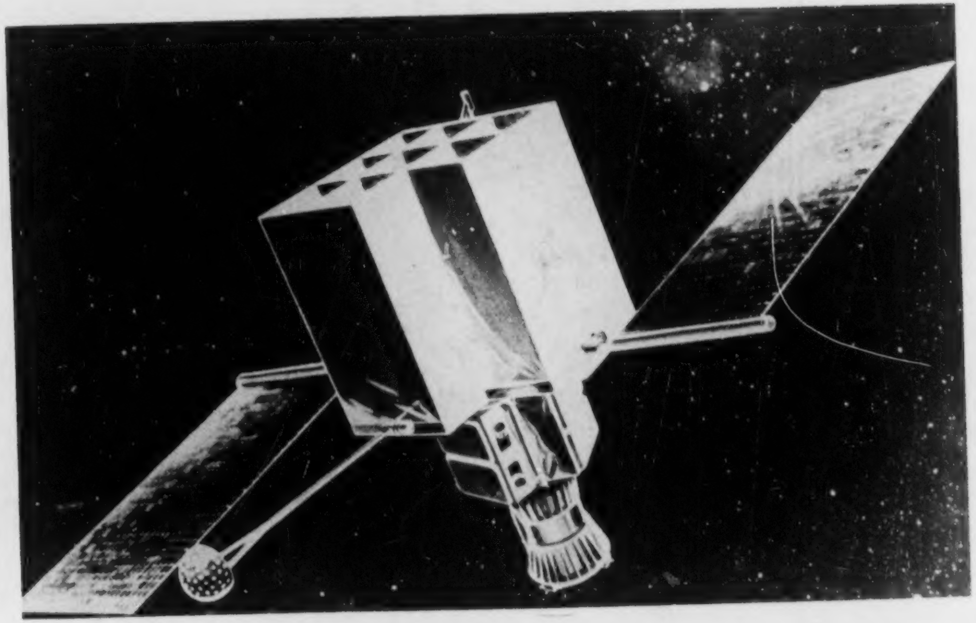

FIGURE 5.7 THE HIGH THROUGHPUT MISSION ON A DEDICATED "SPACE PLATFORM"

earlier descriptions, this mission was called the Large Area Modular Array of Reflectors). Because these sources are diffuse, high resolution in imaging can be sacrificed to facilitate ease of production for the hundreds of x-ray mirrors that will be needed. Three concepts for the mirrors are under study.

At the foci of the telescopes, x-ray sensors will collect the images and record the spectra of the cosmic x-ray sources. Imaging data will show the density of the sources, while the spectra will show the temperature (at low spectral resolution) and composition (at moderate and high spectral resolution) of the sources. The composition of gas heated by supernova explosions should reveal the extent of nuclear processing that has occurred in the inner portions of our galaxy as compared to the outer portions, while the composition of intergalactic gas will show evolution since nearly the beginning of time.

Status. HTM is in the class of moderate missions that will require spacecraft capabilities comparable to those available from an MMS. The mission will require a lifetime of 5 to 10 years, and it is likely that the first integration of HTM with its platform will only involve about half of its telescope modules. As more modules are developed, they will be integrated with the mission at 2-year service intervals.

This integration scenario will only be possible if there is a Space Station, with the necessary platform servicing and integration support capabilities, available to support the mission.

Operations. HTM will conduct a series of observations proposed by investigators from around the world. HTM is a good candidate for a joint mission between NASA and the European Space Agency, and if the program develops as a cooperative effort, control will probably be shared. Many of the detectors in HTM will require replenishment of gases and cryogens that are necessary for instrument operation. The service interval will be on the order of 2 years and will require transportation from HTM's operational orbit to the Station and back.

Advanced Low-Energy Gamma-Ray Explorer (ALEGRE)

Among the astrophysical phenomena that produce low-energy gamma-rays are the annihilation of electrons and anti-electrons, from the decay of radioactive nuclei, and the motion of energetic electrons in extremely strong magnetic fields. In addition, there are numerous continuum sources of broad-band emission and emission far from thermal equilibrium as extremely energetic electrons collide with visible light, radio waves, and even weak, interstellar magnetic fields. Taken together, this wide variety of emission mechanisms provides a powerful set of diagnostic tools for the study of high-energy astrophysical objects, such as compact binary systems, pulsars, novae, supernova, and active galactic nuclei.

Future observations from the Gamma-Ray Observatory (GRO) can be expected to increase considerably the number and variety of objects that will require detailed observations in this energy range. To perform such detailed studies, instruments with significantly improved spectroscopic and imaging capabilities will be needed. ALEGRE is a mission proposed to carry instruments with excellent resolution to complement GRO and to further investigations begun by the GRO survey.

Mission Instruments. Whether the payload consists o a single instrument combining spectroscopy and imaging capabilities or two instruments, each optimized for one of these objectives, is a question that cannot be answered until a more detailed study is carried out. For the purpose of this document we have taken a baseline of two instruments. The first is a high-resolution spectrometer with a modest angular resolution, and the second is a high-angular-resolution scintillator experiment using coded-aperture imaging. (Because gamma rays are too energetic to be reflected, even at grazing angles, an image will be formed by blocking out parts of the field of view. This is called coded-aperture imaging.) Together, these instruments will allow simultaneous high-sensitivity measurements of narrow-line, broad-line, and continuum radiation.

Status. This mission would be part of the Explorer series, and in the Proteus concept, it would replace another Explorer instrument that had completed its mission after 3 or 4 years of operation.

In this concept, the Proteus platform would be retrieved from its operational orbit with the OMV and brought to the Space Station, where the old instrument would be removed and placed in storage until a later Shuttle would be available to return the instrument to the ground. An earlier Shuttle would have brought up the ALEGRE instruments which would be taken out of storage, charged with cryogens, and integrated with the Proteus platform. Finally, the platform and ALEGRE would be transported by the OMV to their operational orbit where the missions would begin.

Operations. The combined instrument complement would be operated under ground control to conduct surveys or carry out detailed studies of individual sources. The choice of observing strategy would depend on the imaging capabilities such as field of view and angular resolution. The required observing time on any given source or region of the sky would typically be from a few days to a few weeks.

Changes in the observing program could be accomplished by utilizing the servicing capabilities of the Space Station to reconfigure the coded-aperture imaging system and, possibly, to replace the cryogens for the detectors.

Solar Physics Missions

The primary thrust of solar physics in the era of the Space Station will be to develop instruments for the Advanced Solar Observatory attached to the Space Station itself. (These instruments are described in Volume 2.) However, there is one mission that has been defined by the solar physics community as having very high priority, the Solar Corona Diagnostics Mission, which we describe in this section.

In some ways, the corona of the sun is as mysterious to us now as it was to earlier civilizations who were surprised to discover a glowing halo around the Sun during rare total eclipses. Now we know that in white light we are seeing sunlight reflected off electrons in a plasma having a temperature of a million degrees, and with x-ray spectroscopy, we have actually observed the ions that have lost these electrons, allowing us to derive the temperature, density, and velocity structure of the corona.

With this information, we have been able to calculate how much power it takes to sustain the corona and to drive the solar wind, but so far, we have not been able to find out how the power is delivered. The most popular theory of 10 years ago is now known to be wrong, and we are left with the puzzle. We have defined the Solar Corona Diagnostics Mission, (SCDM), to help us understand the origin of the corona and the acceleration of the solar wind.

Mission Instruments. The instrumentation for SCDM was selected in 1981. A White Light Coronagraph will measure the electron density and the evolving form of the corona, record transient events, and permit solar physicists to infer the global magnetic structure from the density measurements. A Soft X-ray Imaging Telescope will show the evolving form of the corona, provide plasma temperatures and pressure, and record the coronal manifestations of newly emerging magnetic flux. The third instrument, a Resonance Line Coronagraph, will measure coronal plasma properties and systematic velocities as a function of distance. The fourth instrument, an Extreme Ultraviolet Diagnostic Spectrometer, will measure systematic velocities and plasma properties of the corona, from the coronal transition region into the cooler, denser portions of the Sun's atmosphere, in order to define the varying lower boundary of the inner corona and solar wind. The fifth instrument will be a magnetograph to obtain the magnetic field at the photosphere. The magnetic field governs the form and possibly the overall dynamics of the corona, and this information will be essential for the success of the mission.

Status. SCDM can be accommodated with any platform that has at least the capabilities of Proteus. In the Proteus concept, SCDM is a candidate to be the first mission on the second Proteus platform, and, like XTE, it would probably be integrated with its platform in space.

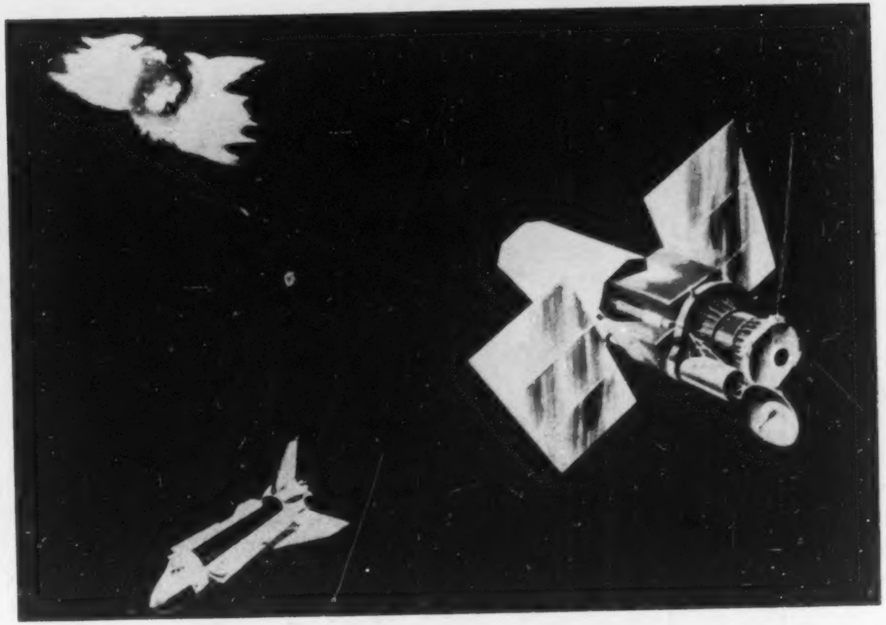

FIGURE 5.8. THE SOLAR CORONA DIAGNOSTICS MISSION

Operations. The minimum mission duration for SCDM is 3 years. It will be operated as a facility, with data distributed to investigators around the country. There are no consumables, and after 3 years, we expect to bring the mission back to the Space Station for de-integration and replacement with another mission.

Astronomy

The following section describes four astronomy missions that will fly on individual, standardized space platforms. Again, the missions selected for description are not meant to imply any special priority, but rather to indicate the broad range in astronomy missions that are best suited for a platform and to show the broad range in benefits provided by the Space Station system. These benefits include the use of free-flying platforms, the availability of the Orbit Transfer Vehicle, and the servicing capability.

Far Ultraviolet Spectroscope Explorer (FUSE, Columbus)

The universe is composed almost entirely of the two elements hydrogen and helium; the heavier elements that we encounter on Earth every day are present in only the minutest amounts when we look at the universe as a whole. Most astronomy so far has relied upon using the scarce, heavy elements as tracers of the physical state of matter, because hydrogen and helium have their fundamental atomic transitions far in the ultraviolet, beyond the reach of ordinary telescopes. To examine the fundamental emissions from hydrogen and helium, FUSE has been designed as a very powerful observatory capable of making fundamentally new and important observations of nearly all classes of astronomical objects, from local solar system objects to cosmological phenomena.

Mission Instruments. The FUSE instruments will consist of a telescope and two spectrographs designed to conduct observations in the far ultraviolet range. Because normal-incidence optics do not work effectively at short wave-lengths, the telescope will be designed to reflect the ultraviolet light at grazing angles. Two spectrographs provide the high resolution necessary to extract physical information concerning important galactic and intergalactic phenomena such as the state of Jupiter's plasma torus that envelops Io's orbit, the global balance of energy in the coronae of stars, the violent forces acting on the gas between the stars, and the deuterium content of intergalactic material. This last observation is extremely important because deuterium (hydrogen with both a proton and a neutron in its nucleus) is a sensitive probe of nuclear conditions during the formation of the universe.

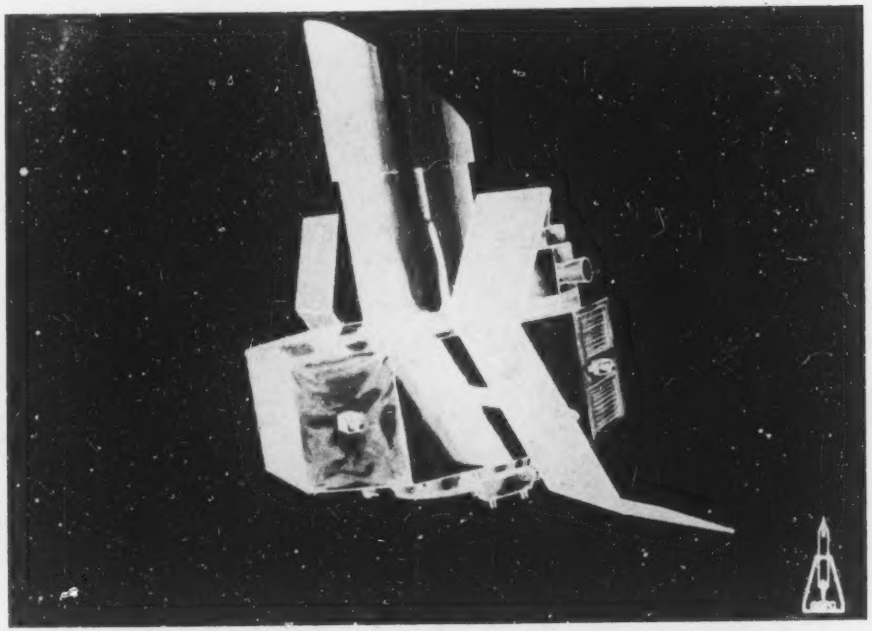

FIGURE 5.9. FAR ULTRAVIOLET SPECTROSCOPY EXPLORER

Status. Like XTE and SCDM, FUSE is likely to be one of the first missions for a dedicated platform, and this makes it likely to be integrated with its platform in space, possibly in the Shuttle. The opportunity to place FUSE on a separate platform, retrievable and serviceable by the Space Station, introduces new possibilities for FUSE. Not only can the cost be reduced through removal of redundant components, but the versatility of the experiment can be extended as well. For example, the spectrograph described above could be exchanged for a low-resolution, grazing-incidence design which would use the same telescope and pointing system. A few years later, a short-wavelength, high-resolution instrument could be flown. Such an approach could keep FUSE on the cutting edge of astrophysics for decades and extend the use of the telescope far beyond anything possible with a dedicated observatory design.

Operations. The observatory will be operated in a sequence of preplanned observations selected from proposals submitted to NASA. Discussions are being conducted to determine whether there is international interest in making FUSE a joint program; if there is, operations may be jointly shared with the international participants.

Starlab

The Hubble Space Telescope is designed to obtain high resolution data over a wide wavelength band, but the types of observations it will perform are limited by its narrow field of view. Since many observations require a large field of view, the Starlab space-based telescope will be developed to fill this need. Current plans call for NASA to be responsible for the space platform, launch, and mission-operations, and for international participants to provide the telescope, scientific instruments, and integration of the Starlab facility.

Mission Instruments. Starlab will be a free-flying, 1-meter astronomical telescope that will obtain wide-field images and long-slit spectra at ultraviolet and visible wavelengths. A Direct Imager Camera will view the central field of the focal plane and record the entire field with little degradation in image quality. The camera will employ filters for spectral definition and a prism for low-dispersion spectra over the full target field. A spectrograph will provide spatially-resolved spectrograms along the length of the slit. The area surrounding the field viewed by the scientific instruments will be used to track stars with the Fine Guidance System.

The Starlab instrumentation makes it possible to study objects with large apparent diameters such as nearby galaxies, clusters of galaxies, supernova remnants, or comets. It will also be used to obtain large statistical samples, such as distance indicators in nearby galaxies, or to isolate targets in crowded fields, such as Cepheids in nearby galaxies. In addition, Starlab will perform survey work such as searching for supernovae in distant galaxies.

Thus, this instrument will complement other space telescopes by providing independent observations of certain objects and by identifying sources for more detailed study.

Status. The long mission duration, susceptibility to contamination, and stringent pointing requirements all call for a free-flying platform to accommodate Starlab. Additionally, Starlab capabilities will be enhanced by the ability to refurbish the mission at the Space Station, and, ultimately, to place the Starlab in geosynchronous orbit to improve its efficiency.

The goal for in-orbit operation life is 5 years, with a total multimission lifetime of over 20 years. On the first mission, planned for the mid-1990s, Starlab will carry the Direct Imager Camera as the sole scientific instrument. On subsequent missions, a refurbished Starlab facility will carry the Long-Slit Spectrograph as well.

Operations. Starlab would be operated by the United States and its international partners as a joint facility, with program options coordinated among the nations.

Orbiting Very-Long-Baseline Interferometry Observatory

Very-long-baseline interferometry (VLBI) techniques have been used by radio astronomers over the past decade to obtain maps of celestial radio sources at previously unrealizable levels of angular resolution--about 1000 times better than the resolution achieved with optical photographs or conventional radio interferometers. Satellite-borne VLBI terminals could provide maps of compact celestial radio sources with finer resolution, less ambiguity, and more efficiency than earth-bound VLBI techniques. High spatial and temporal resolution observations would help unravel the physical processes that govern some of the most enigmatic classes of celestial objects.

Mission Instruments. An orbiting VLBI mission called Quasat has been proposed as an international joint endeavor in space radio astronomy. The Quasat system requires a sufficient signal-to-noise ratio to allow for source detection. Receivers and feeds would be at the focus and operate at frequencies of 22 GHz, 5 GHz, and 1.6 GHz. The spacecraft will utilize a ground-based hydrogen maser frequency standard to derive the onboard frequency reference. Data rates of 144 mbps are expected; all data will be handled in real time.

Status. These spacecraft requirements appear to be within the capabilities of the MMS. The reflector and components which dominate Quasat's configuration could be made compatible with the MMS standard interface.

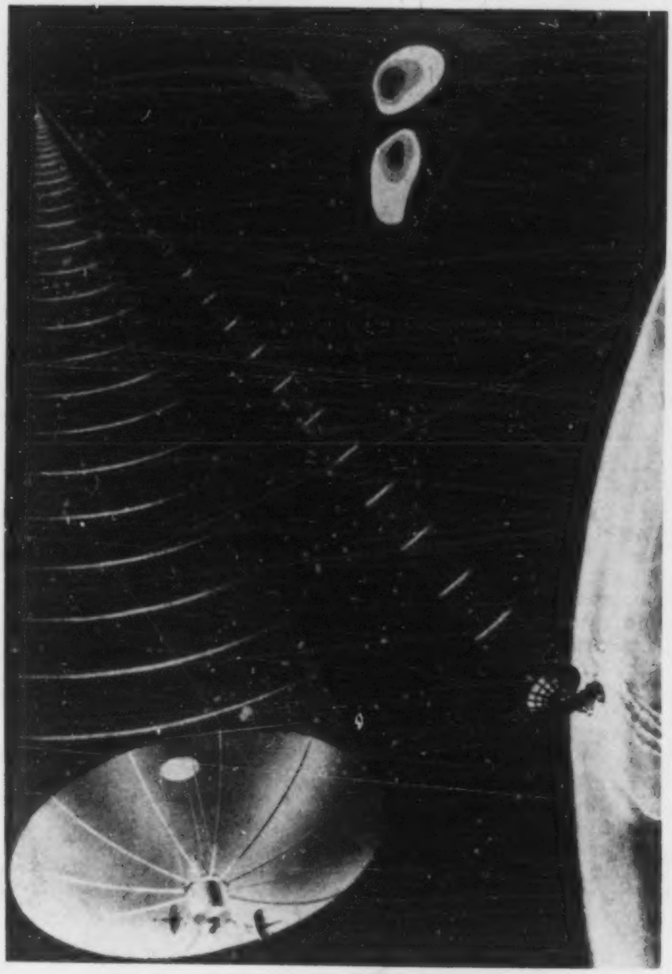

FIGURE 5.10. ORBITING VLBI: HIGH-RESOLUTION MAPS OF CELESTIAL RADIO SOURCES

Because Quasat's orbit is expected to differ substantially from that planned for the Space Station, no interaction with the Space Station in terms of servicing or assembly is foreseen. However, prototype systems can be developed and tested by deploying them from the Space Station.

Operations. In addition to quasars, exotic stars such as pulsars, X-rays stars, flare stars, and SS-433 type objects will be observed. These all display highly energetic phenomena. The time scales for variation are very short, in some cases only hours, so that observations of these stars is an ideal application of Quasat's rapid mapping capability. Quasat's sensitivity would allow the study of the fine structure of about 10,000 celestial objects, including:

- 7000 quasars
- 1500 galactic nuclei
- 1000 "empty field" sources
- 400 interstellar masers
- 100 radio stars.

Astrometric Explorer

An exciting prospect for a specialized space platform mission is the Astrometric Explorer, an optical telescope capable of measuring star positions very precisely. With high-precision position measurements, the parallax and proper motion of the most distant stars in our galaxy can be measured. These measurements will allow the dynamics of our galaxy to be established and correlated with optical and radio maps.

The scientific benefits that may be expected from this precision include the precise measurement of the following:

- Absolute distances of galactic stars
- Distances to interstellar absorption features
- Structural properties of spiral arms
- Galactic dynamics
- Binary masses
- Mass-color-luminosity relation of main sequence stars
- Space motions of nearby external galaxies.

The Astrometric Explorer is well suited to installation on an MMS or Proteus-class platform. A mission duration of 3-5 years should be adequate to achieve the goals of the Astrometric Explorer Mission.

SUMMARY

We believe that the Space Station will allow significant increases in the efficiency with which we conduct the Astrophysics Program by augmenting the servicing capability for observatories and platforms. The continuum of platforms, along with effective Space Station servicing, will provide a proper mix of flight opportunities for free-flying science experiments.

30

WORKSHOP ON
ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on Space Platforms for Astrophysics

Dr. Louis J. Kaluzienski, Chairman
Dr. Paul A. Blanchard
Dr. Roger D. Bourke
Dr. Jesse D. Bregman
Dr. Alan N. Bunner
Dr. Webster Cash
Mr. Harry D. Cyphers
Dr. Sara Heap
Mr. William D. Hibbard
Mr. Peter Jasper
Dr. Knox S. Long
Dr. Richard A. McCray
Dr. Enrico Mercanti
Dr. Robert Novick
Dr. Stephen J. Paddack
Dr. Thomas A. Prince
Mr. Joseph Purcell
Dr. Robert E. Stencel
Mr. David H. Suddeth
Dr. Jean H. Swank
Dr. Bonnard J. Teegarden

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: C:DLpv

Honorable Don Fuqua
Chairman
Committee on Science and Technology
House of Representatives
Washington, DC 20515

JAN 07 1986

Dear Mr. Chairman:

Enclosed, for the information of the Committee, is a copy of the report sent to the Speaker of the House pursuant to Section 202 of P.L. 96-302, as amended, with respect to the interaction of NASA Industrial Application Centers with the Nation's small business community.

Sincerely,

John F. Murphy
Assistant Administrator
for Legislative Affairs

Enclosure

cc: Honorable Manuel Lujan, Jr.

NASA

National Aeronautics and
Space Administration

Washington, D C
20546

Office of the Administrator

JAN 3 1986

Honorable Thomas P. O'Neill, Jr.
Speaker of the House of Representatives
Washington, DC 20515

Dear Mr. Speaker:

Pursuant to Section 202 of P.L. 96-302, as amended, the Small Business Development Center Act, I am pleased to transmit to you the annual report of the National Aeronautics and Space Administration on the performance of our industrial application centers and on their ability to interact with the Nation's small business community.

Sincerely,

William R. Graham

William R. Graham
Acting Administrator

Enclosure

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Annual Report Under Section 202 of Public Law 96-302, As Amended, for 1985

In 1985 the National Aeronautics and Space Administration continued to fund and enhance its network of technology dissemination centers, including seven (7) Industrial Applications Centers (IACs) and two (2) State Technology Applications Centers (STACs). This network continues to be a major program element in supporting NASA's efforts to transfer to the industrial and business communities aerospace-related technology generated through NASA's research and development programs. Small businesses continued to constitute approximately 70 percent of the total client base for the technology transfer efforts of the IACs and STACs.

NASA vigorously sustained its efforts to comply with the mandate under Section 202 of Public Law 96-302 through activities in support of the Small Business Development Center (SBDC) program and related efforts to strengthen its efforts in the Small Business Innovation Research (SBIR) program. There continued to be substantial variation in the makeup and effectiveness of individual SBDCs as well as in the quality and content of submissions emanating from SBIR participants. Our effort to assist in these program areas may be seen in the following examples.

At NERAC (New England Research Applications Center), the NASA IAC in Storrs, Connecticut, major efforts were undertaken to improve technology awareness among small businesses through collaboration with the SBDC program. Such efforts included the initiation and completion of conferences at a number of locations (e.g. Boston, Chicago, Pittsburgh, Philadelphia, Hartford and Storrs) which provided opportunities to explore ways of matching small business needs with possible solutions based on aerospace and other relevant technologies. Other NERAC efforts included the performance of several hundred highly specialized technology searches (75 of which were submitted through various SBDC offices) for the benefit of specific participating small business firms. Over the past year, NERAC began work with 175 additional firms under the SBDC program, thereby extending its total outreach to more than 5000 small businesses.

The NASA IAC at the University of Southern California continued its efforts in support of the SBDC and SBIR programs, performing a total of 108 technology searches for small firms in connection with SBDC and SBIR activities. This IAC continued its outreach activities through SBDC affiliate organizations in Idaho, Colorado, Washington, California and Nevada through the provision of online computer assistance training and related search activities.

The IAC in Indiana expanded its earlier activities under the state's Technology 2000 program to include the provision of technology searches to 54 small firms. Twenty-six (26) of these were incorporated into larger scale "engineering studies" some of which served as the basis for specific R&D planning and implementation activities.

In addition to conducting search activities for small business, the IAC in North Carolina sponsored six one-day workshops on R&D funding sources available to small businesses. This center also sponsored a major two-day conference on innovation and small business development.

The Applications Centers in Florida, Kentucky, Oklahoma and Pennsylvania each participated in a number of intra-state conferences and workshops relating to the provision of assistance to small business firms in the area of high technology and innovation. These centers also continued to remain active in providing technology searches to small business firms within their states.

NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546

Reply to Attn of
C:DLpv

Honorable Don Fuqua
Chairman
Committee on Science
  and Technology
House of Representatives
Washington, DC 20515

FEB 11 1986

Dear Mr. Chairman:

Enclosed, for the information of the Committee, is a copy of the report sent to the Speaker of the House pursuant to Section 2732 of the Deficit Reduction Act/Competition in Contracting Act, P.L. 98-369, regarding the implementation and performance of our Competition Advocacy Program.

Sincerely,

Jack Murphy

John F. Murphy
Assistant Administrator
  for Legislative Affairs

Enclosure

cc: Honorable Manuel Lujan, Jr.

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COMMITTEE ON SCIENCE
AND TECHNOLOGY

NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546
Office of the Administrator

FEB 6 1986

Honorable Thomas P. O'Neill, Jr.
Speaker of the House of Representatives
Washington, DC 20515

Dear Mr. Speaker:

Pursuant to Section 2732 of the Deficit Reduction Act/Competition in Contracting Act, P.L. 98-369, I am pleased to transmit to you the annual report of the National Aeronautics and Space Administration on the implementation and performance of our Competition Advocacy Program.

Sincerely yours,

William R. Graham

William R. Graham
Acting Administrator

Enclosure

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FY 1985 COMPETITION ADVOCACY REPORT
TO
THE CONGRESS OF THE UNITED STATES

The National Aeronautics and Space Administration Competition Advocacy Report is compiled and submitted in accordance with the Competition in Contracting Act of 1984. For the fiscal year ending September 30, 1985, approximately 76% of procurement obligations were made competitively. A detailed breakdown of procurement statistics for fiscal year (FY) 1985 is included later in the report.

This report is divided into six parts: (1) actions taken to achieve full and open competition in NASA procurement during FY 1985; (2) a summation of the accomplishments during FY 1985; (3) remaining barriers to full and open competition in NASA procurement; (4) required new initiatives to increase competition; (5) a narrative analysis, along with two charts, which will provide overall statistical data; and (6) NASA procurement competition goals for the fiscal year in progress.

PART I
ACTIONS TAKEN TO ACHIEVE FULL AND OPEN COMPETITION

NASA has initiated several actions to enhance competition subsequent to implementation of the Competition in Contracting Act (CICA), Public Law 98-369. Institutionalization of the competition advocacy process, increased personal accountability for competition, and training were the key elements for achieving success for the Competition Advocacy Program. Further clarification of each of these three areas follows.

A. NASA appointed the Chief Engineer as the Competition Advocate. The purpose for this assignment was to enhance system discipline for technical requirements initiators relative to competition. Technical considerations frequently are a major factor contributing to noncompetitive procurements. As the Competition Advocate, the Chief Engineer and center competition advocates have the responsibility and authority to challenge competition aspects of technical requirements. The Chief Engineer has established in his organization an office to oversee the Competition Advocacy Program. This office reviews and recommends approval/disapproval on all noncompetitive procurements over $10 million, reviews selected competitive actions to eliminate constraints that could lead to less than full and open competition, performs an annual review of each field center's competition activities, and reviews other selected actions.

Designating the Deputy Center Directors as center competition advocates places the function at a sufficiently senior organizational level to assure appropriate management attention for this important program. In achieving its research and development mission, NASA focuses on managerial and technical excellence as a prerequisite for mission success. The Competition Advocacy Program will draw on this talent at Headquarters and the centers to achieve the objectives of the program.

B. NASA has issued a management instruction for implementing the NASA Competition Advocacy Program. Each field center subsequently promulgated policy documents to implement the program at the center. Personal accountability for achieving competition has been realized through formal assignment of competition advocacy duties to directors, managers, and supervisors within the technical organizations at NASA centers. In addition, most of these personnel who are directly involved in establishing requirements have specific objectives for achieving competition in their performance appraisal plans.

C. NASA has provided specialized procurement training to personnel involved in the acquisition process. A training session was provided to senior management, and a more comprehensive seminar was prepared and presented to middle managers. An in-depth course was provided for procurement personnel, and a tailored course was also designed for scientists, engineers, and others who are involved in generating requirements. A major by-product of this training on the Competition in Contracting Act requirements was the realization, by both the technical and procurement communities, that neither could develop a competitive procurement package without the other. The resulting cooperation has fostered better statements of work and increased competition. The training sessions served another useful purpose in breaking down attitudinal barriers. By developing an organizational awareness of the need for and value of competition, both the technical and procurement personnel are cooperating to accomplish the mission.

PART 2
ACCOMPLISHMENTS DURING FISCAL YEAR 1985

NASA had a number of accomplishments for the Competition Advocacy Program during fiscal year 1985. As indicated in Part 1, major accomplishments during the year were establishment of the organizational framework and operating procedures for competition advocacy at Headquarters and the centers. A significant number of the agency's management, technical, and procurement personnel received training on the Competition in Contracting Act requirements during the year.

Specific actions to increase competition that were accomplished include:

- Centers explored the concept of reverse engineering in order to develop specifications for future competitive procurements. The use of draft solicitations, third-party review of requirements, and technical review panels for assessing specification and statement of work appropriateness for competition were also looked into. The primary purpose of these activities has been to improve the quality of NASA's technical requirements. We will be following up on these efforts in the coming year.

o Increased use of sources sought synopses was strongly encouraged by Headquarters as a market survey technique that could enhance competition. We will be evaluating the success of this approach during FY 1986.

o With respect to procurements that are currently noncompetitive, centers are developing initiatives to foster competition in the future, where feasible, and mechanisms for following up on these initiatives.

o Another initiative in the area of market research involves offering vendors opportunities to demonstrate the capabilities of their products on-site at a NASA center, while publicizing these demonstrations in advance to inform potentially interested center personnel of the time and place for these demonstrations.

o With regard to ADP procurement, one center has an area in their computer facility where various types of personal computers are available to contractors to demonstrate the compatibility of their products (keyboards, printers, personal computers, software etc.) with other equipment and with the center's host computer.

o Technical documents relating to NASA's major programs were made available through reference libraries, bulletin boards, reading rooms, etc. Prospective contractors were encouraged to use these facilities to develop the technical background to compete on future NASA procurements.

PART 3
BARRIERS TO COMPETITION

Barriers to competition exist in NASA. These are summarized below.

A. Some technical requirements initiators continue to structure their procurements in terms of the best possible product or service rather than in terms of the minimum acceptable requirement.

B. Some technical requirements initiators have a reluctance to change from incumbent contractors and go through the difficulties of orienting a new firm unknown to the engineer or scientist.

C. Problems exist with respect to proprietary data and the lack of adequate technical data packages. Many of NASA's procurements are for highly complex products and systems in limited quantities, and procurement of reprocurement data packages may not be economically feasible for these requirements.

D. Delays in obtaining appropriated funds restrict the amount of time available for procurement obligation. This in some cases necessitates extending existing contracts or awarding new contracts on a noncompetitive basis.

E. Certain procurements are dictated by other agencies, i.e., security sensitive requirements for joint NASA/Department of Defense projects are often deemed to be available from only one qualified source.

F. Frequently the ability to compete is constrained by earlier decisions to acquire particular data processing hardware or software. While this earlier decision may have been competitive, subsequent requirements to update or modify the system cannot be realistically competed due to the lack of interchangeability of hardware and software among companies. In the area of proprietary ADP systems or hybrid scientific ADP systems, this approach also limits the ability to compete maintenance requirements for automatic data processing systems once acquired.

G. Some large complex systems exist where the original equipment manufacturer is the only firm with the necessary engineering expertise, corporate knowledge, and manufacturing and test equipment required to perform the effort.

PART 4
INITIATIVES TO INCREASE COMPETITION

The following intiatives for enhancing competition are proposed for fiscal year 1986.

A. In order to overcome the barriers related to overstated requirements and the reluctance to work with contractors that NASA requirements initiators have not worked with in the past, we will conduct additional training in these areas. We will also continue to emphasize the need for early procurement planning and involvement of procurement personnel at the outset of the requirements determination process.

B. We will encourage the centers to identify procurement strategies for acquiring technical data packages in order to compete future requirements.

C. For interagency procurements involving security-sensitive requirements and for which NASA is the procuring agency, we will explore the possibility of competition among those companies having the requisite security clearances and technical capabilities.

D. With respect to automatic data processing procurements, it may not be feasible to replace existing systems. However, we will attempt to develop future requirements to maximize competition by requiring interchangeability and the capability for maintenance by third parties.

E. Where future requirements are of sufficient magnitude, efforts will be made to seek second sources. Examples of this initiative during fiscal year 1986 are the plans to develop a second source for the procurement of solid rocket motors and for the Space Shuttle Main Engine high pressure turbopumps.

F. We have directed certain centers to develop plans for competing requirements which had previously been obtained on a noncompetitive basis. An example currently being considered is development of a competitive procurement for some portions of the orbiter logistics function, including equipment repair and spares procurement.

G. We will establish a clearing-house function in the Competition Advocate's Office in order to make available to all centers the initiatives and good approaches for competition developed at other centers.

H. There are several areas that we will look into further in order to encourage competition. These include reverse engineering, the use of draft solicitations, third-party (under contract) review of specifications, presolicitation meetings, and the formation of technical review teams to review a center's specifications and statements of work.

I. We will encourage our prime contractors to establish plans to maximize competition in the subcontract area.

PART 5
COMPETITION STATISTICS

The following Figure 1 is submitted in accordance with an agreement reached among agency Competition Advocates at a meeting sponsored by the Office of Federal Procurement Policy. Figure 1 includes actions with business firms, educational and nonprofit organizations, utility firms where competition was available, and procurements outside of the United States. Figure 2 lists exclusions from Figure 1, including awards under Section 8(a) of the Small Business Act, intergovernmental awards, grants and cooperative agreements, utility procurements for which competition was not available, and the procurements with the California Institute of Technology for the operation of the government-owned Jet Propulsion Laboratory.

FIGURE 1

FISCAL YEAR 1985

PROCUREMENT ACTIONS OVER $25,000

	NUMBER OF ACTIONS	PERCENTAGE OF AVAILABLE ACTIONS	DOLLAR OBLIGATIONS (000)	PERCENTAGE OF AVAILABLE DOLLARS
I. Actions Available for Competition				
A. Actions Competent[1]	12,504	72%	$4,975,769	76%
B. Follow-on To Competed Actions[2]	336	2%	231,078	4%
C. Actions Not Competed	4,615	26%	1,311,135	20%
D. Total Available	17,455	100%	6,517,982	100%
II. Actions Excluded[3]	8,702	xxxx	1,502,122	xxxx
III. Total Actions	26,157	xxxx	$8,020,104	xxxx

PROCUREMENT ACTIONS UNDER $25,000

	NUMBER OF ACTIONS	PERCENTAGE OF AVAILABLE ACTIONS	DOLLAR OBLIGATIONS (000)	PERCENTAGE OF AVAILABLE DOLLARS
I. Actions Available for Competition				
A. Actions Competed[1]	40,687	44%	$ 111,542	65%
B. Actions Not Competed	50,952	56%	59,028	35%
C. Total Available	91,639	100%	170,570	100%
II. Actions Excluded[3]	3,058	xxxx	107,369	xxxx
III. Total Actions	94,697	xxxx	$ 277,939	xxxx

NOTE 1. Includes the following three categories of competed actions under CICA: a) Full and Open Competition; b) Less than Full and Open Competition - more than one offer/bid received; and C) Full and Open Competition - only one responsible offer/bid received. It also includes the CICA categories of competition: (i) Two-step Formal Advertising, (ii) Other Formal Advertising, and (iii) Negotiated Competitive.

NOTE 2. If not applicable, may be deleted from form.

NOTE 3. Agencies including "other" exclusions (per OFPP instructions) should list each category separately as subelements in .his item II.

FIGURE 2

EXEMPT PROCUREMENTS AS PER OFPP LETTER

PROCUREMENT ACTIONS OVER $25,000

ACTIONS EXCLUDED	NO. OF ACTIONS	DOLLAR OBLIGATIONS (000)
8(a) Awards*	2,427	$ 126,132
Intragovermental	1,387	418,773
Grants & Cooperative Agreements	3,456	170,700
Utilities	208	61,886
JPL**(Ref. Note 3 figures 1 & 2)	1,224	724,631
TOTAL	8,702	$1,502,122

PROCUREMENT ACTIONS UNDER $25,000

ACTIONS EXCLUDED	NO. OF ACTIONS	DOLLAR OBLIGATIONS (000)
8(a) Awards	51	$ 929
Intragovernmental	2,998	106,337
Grants & Cooperative Agreements	9	103
TOTAL	3,058	$ 107,369

* NASA (Lewis Research Center) is currently involved in evaluation of proposals for a major 8(a) award for Consolidated Logistics and Administrative Services Support (CLASS). This award is estimated to be $50M for the basic period plus options.

** The Jet Propulsion Laboratory (JPL) is a Government-owned research and development facility, operated for NASA by the California Institute of Technology. The Laboratory carries out research programs and flight projects and conceives and executes advanced development and experimental engineering investigations to further the technology required for the Nation's space program. Funding for JPL consisted of $724.6M of which JPL expended approximately $360M for subcontracts. Of this subcontracted amount, $247M or 68.6% was competed.

PART 6

Since 1981, NASA has competed 70-76% of the obligated dollar value of contracts per year. In FY 1984, the value was 73% and increased to 76.1% in FY 1985. This significant improvement was the result of increased emphasis on competition. The primary objective during FY 1986 will be to seek second sources and/or compete as much of the current systems requirements as possible to the extent that quality, safety and reliability will not be affected.

With respect to procurements where the competition requirements of the Competition in Contracting Act apply, i. e., those over the small purchase threshold, currently $25,000, NASA competed 76% of procurement obligations and 72% of procurement actions in fiscal year 1985. Based on this performance, NASA's goal for fiscal year 1986 is to increase competition for procurements over $25,000 in both obligations and procurement actions. We believe these are realistic goals considering NASA's past experience and our initiatives for the year.

In order to maximize competition throughout NASA, we have also analyzed the extent of competition for small purchases. This analysis indicates that for FY 1985, NASA competed 65% of its small purchase obligations and 44% of small purchase actions. In addition to our other initiatves, we intend to emphasize competition in small purchases during FY 1986. Our goal will be to compete 55% of small purchase actions which will ultimately contribute towards the overall increase in obligations.